C

Cakravala Method

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Let us consider the equations (i) $3x = 6$ and (ii) $5y = 2$ in the two variables x, y. We recognize at once the (integer) solution $x = 2$ for equation (i) and further note that there can be no y in the set $\mathbf{N}: = \{1, 2, 3,\ldots\}$ of natural numbers which satisfies equation (ii), since the constant term 2 on the right-hand side of equation (ii) is not an integral *multiple* of (i.e., is not divisible by) the coefficient 5 of the variable y therein. Leaving these two simple examples of linear equations in a single variable, let us take up the following linear equation involving two variables x and y:

$$px - qy = m \tag{1}$$

where the coefficients p, q and the constant term m belong to the ring $\mathbf{Z}$ of the usual integers. $\ldots -3, -2, -1, 0, 1, 2, 3, \ldots$. Clearly, for (Eq. 1) to have a solution $x = a, y = b$ with a, b in $\mathbf{Z}$, it is necessary that any common divisor t of p and q (i.e. any t in $\mathbf{Z}$ dividing both p and q) must be a divisor of m as well. Thus the greatest common divisor (g.c.d. in brief) d of p and q denoted as (p, q) in symbols must also divide m. Now, a well-known algorithm of Euclid's for finding (in finitely many steps) the g.c.d. of any two given integers p, q enables us to write their g.c.d. d in the form $d = pa + qb$ with suitable a, b in $\mathbf{Z}$, and we are led to the solution for (Eq. 1) in integers $x = am/d, y = -bm/d$. We should not fail to mention that an alternative approach to solving (Eq. 1) is to expand the rational number q/p (for $p \neq 0$) as a simple continued fraction. For example, if $p = 3$, $q = 11$ in (Eq. 1), then $q/p = 11/3$ has the continued fraction expansion $(3 + 1)/1 + 1/2$ whose "penultimate convergent" $(3 + 1)/(1 = 4/1)$ solves this special case of (Eq. 1) with $x = 4$, $y = 1$.

Solving linear equations such as (Eq. 1) in two variables or in more variables often opens the door to cracking interesting puzzles or even settling serious problems! A clear description of the method of solving (Eq. 1) is available in *Āryabhaṭīya*, a Sanskrit text of the (fifth or) sixth century AD. (According to Ian Pearce (2002), the mathematical part of *Āryabhaṭīya* covers arithmetic, algebra, plane trigonometry and spherical trigonometry and also contains continued fractions.) As observed by André Weil, this is also "the first ever explicit description" of the general solution in integers for (Eq. 1) from anywhere, except China. In subsequent Sanskrit treatises, this method came to be known as the *kuttaka* (pulveriser) method, but it might not be fair to attribute the same with authority to Greek mathematicians granting the familiarity of Indian astronomers with developments in Greek mathematics until then. It is interesting to learn from Weil how, in utter disregard or (possible) ignorance of the remarkable application of the *kuttaka*

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in India and of the connection with the seventh book of Euclid's *Elementa*, Bachet ventured to insert (in the second edition of his book *Problèmes plaisants et délectables*) a strong claim to the *kuttaka* method as his own. Before attempting to say anything about the *cakravāla* method, let us see how the *kuttaka* method is applied.

Equation 1 can be rewritten as an (equivalent) "congruence" relation modulo the integer q, namely as $px \equiv m(\text{mod } q)$; we might recall here the customary notation, for a, b, c in **Z**, that $a \equiv b(\text{mod } c)$ exactly when c divides a–b. Whenever d, the g.c.d. of p and q divides m, we can find, by Euclid's algorithm, an integer x such that px–m (equals qy and hence) is divisible by q, i.e., $px \equiv m \text{ (mod } q)$. The *kuttaka* precisely enables one to find the form of the general solution of this congruence (whenever (p, q) divides m). Take, by way of an example, the congruence $3x \equiv 1(\text{mod } 7)$. Since the g.c.d. $(3, 7)$ equals 1, the congruence is indeed solvable. Now $3 \times (-2) = -6 \equiv 1(\text{mod } 7)$ and so, on multiplying both sides of the congruence by -2, we get $-6x \equiv -2 \text{ (mod } 7)$ which is the same as $x \equiv 5 \text{ (mod } 7)$. The *kuttaka* thus tells us that any integer of the form $7n + 5$ for arbitrary n in **Z** satisfies the congruence $3x \equiv 1(\text{mod } 7)$.

From linear equations in x and y, let us move on to (much more non-trivial) equations of degree 2 in two variables, e.g. $x^2 - Ny^2 = 1$ for N in **N**. If $N = M^2$ with $M \in \mathbf{Z}$, the solution in integers x, y of this equation can be immediately found by factorising the left hand side and rewriting the equation as $(x + My)(x - My) = 1$ and hence as $(x + My) = (x - My) = \pm 1$. However, if $N = 2$ or any square-free integer (i.e. not divisible by the square of any prime number), then one could ask for all integers y such that $Ny^2 + 1$ is the square of an integer and, in other words, ask for solutions in integers x, y of

$$x^2 - Ny^2 = 1 \tag{2}$$

which indeed looks harder and is known as Pell's equation (ever since Euler attached Pell's name to it *by* mistake!).

For a while, let the square-free integer $N > 1$ be kept fixed in our general discussion and let, for any given integer m, the given triple $(x, y; m)$ stands for a solution in integers x, y of the more general diophantine equation

$$x^2 - Ny^2 = m \tag{3}$$

We can clearly identify, for any $t \neq 0$ in **Z**, the triple $(tx, ty; t^2m)$ with $(x, y; m)$.

Under the heading *Vargaprakrti*, (Eq. 3) was investigated by the Indian mathematician ▶ Brahmagupta (seventh century AD) who used his bhavana rule to get non-trivial solutions for (Eq. 2) in integers for several cases of N (and, in particular, for $N = 92$ or 83, solutions given by $(1151)^2 - 92 \times (120)^2 = 1, (82)^2 - 83 \times 9^2 = 1$. The *bhavana* (composition) rule gives, for two given triples $(x, y; m)$ and $(z, t; n)$, their product (or composite) $(x, y; m)(z, t; n)$ by the formula

$$(x, y; m)(z, t; n) := (xz \pm Nyt, xt \pm yz; mn) \tag{4}$$

Written in expanded form, this leads us to the composition formula

$$\begin{aligned}&\left(x^2 - Ny^2\right)\left(z^2 - Nt^2\right)\\ &\quad = (xz \pm Nyt)^2 - N(xt \pm yz)^2\end{aligned} \tag{5}$$

expressing, in modern parlance, the multiplicative property of the norm form $x^2 - Ny^2$ in two variables x and y.

The square-free integer N associated with the triple $(x, y; m)$ for (Eq. 3) was referred to as the *gunaka* (or *prakrti)* and the integer m therein as *ksepa* (additive). Brahmagupta knew how composition of a triple $(x, y; m)$ with a triple $(p, q; 1)$ with the same *gunaka* N leads to a triple $(x', y'; m)$, while the product $(x, y; m)(x, y; m)$ is again a triple $((x^2 + Ny^2)/m, \ 2xy/m; 1)$ provided $(x^2 + Ny^2)/m$ and $2xy/m$ are both in **Z**. For $m = -1$ or ± 2, composition of $(p, q; m)$ with itself leads to $(p^2 + Nq^2, 2pq; 1)$ or $((p^2 + Nq^2)/2, pq; 1)$, respectively. While the composition formula (Eq. 5) occurs explicitly in

Brahmagupta's work, special cases of the same for $N = 3$, $z = 5$, $t = 3$ may have been applied by Archimedes to obtain approximations to $\sqrt{3}$ by rational numbers, according to Weil.

We now give an example to see how the *bhavana* rule helps in solving (Eq. 2). Let us take Brahmagupta's investigation of the case $N = 83$ itself. The natural number "closest" to the *vargamoola* (square root) $\sqrt{83}$ of 83 is 9 and the relation $9^2 - 83 \times 1^2 = -2$ is the same as the triple (9, 1; −2) corresponding to the value 83 for N. Composing this triple with itself according to *bhavana* as in (Eq. 4), we note that $((9\times 9)+(83\times 1\times 1))^2 - 83((9\times 1)+(9\times 1))^2 = 4$, giving the "square" of (9,1; −2) as (164, 18; 4). On division throughout by 4, the last-mentioned triple leads exactly to (82, 9; 1) which is a solution (as discovered by Brahmagupta) for (Eq. 2) with $N = 83$. In H. T. Colebrook's book, *Algebra with Arithmetic and Mensuration, from the Sanscrit of Brahmegupta and Bháscara*, one can find an entire section dealing with Brahmagupta's investigations on *Vargaprakrti*. Brahmagupta could find extremely accurate values for $\sqrt{N}$ using his solutions for (Eq. 2). According to Ian G. Pearce (2002), "this contribution is of huge interest as it is essentially the same method rediscovered and used by Newton and Raphson around 1690, which is known as the Newton-Raphson iterative method".

Despite Brahmagupta's admirable results, the general solution of (Eq. 2) is still not at hand! The brilliant *cakravāla* (cyclic) method for the general solution of (Eq. 2) has been located in the work of Bhaskara much later, around the twelfth century. Almost the same description of the *cakravāla* is provided in a commentary written around the eleventh century by "an otherwise unknown author" Jayadeva, leaving it open (for anyone) to identify the real inventor of the *cakravāla*. We shall now give a brief description of the method and an illustrative example.

The idea of the method is to start from a triple $(p_0, q_0; m_0)$ with "small" m_0 and use the bhavana to get a triple $(p_1, q_1; m_1)$ with m_1 "small" again and eventually, in finitely many steps, hit upon a triple $(u, v; r)$ with $r = 1, -1, \pm 2$; for $r = 1$, (Eq. 2) is solved with $x = u$, $y = v$ but in the three remaining cases of r, composition of $(u, v; r)$ with itself yields a solution for (Eq. 2) as explained earlier (noting that the *gunaka* N is kept fixed all the while). For the triple $(p_0, q_0; m_0)$ at the start, p_0 is chosen such that p_0^2 is the square closest to N and q_0 is taken as 1 so that $m_0 = p_0^2 - N$. Next, the integer x_0 is chosen to satisfy the congruence $x_0 \equiv -p_0 (\mathrm{mod}\ m_0)$ besides ensuring at the same time that $x_0^2 - N$ is "small" and in fact, more precisely, least in absolute value among all possible choices for x_0 with $x_0 \equiv -p_0 (\mathrm{mod}\ m_0)$. Then the triple $(p_1, q_1; m_1)$ is defined as the composite

$$(p_0, q_0; m_0)\left(x_0, 1; x_0^2 - N\right) = \left(\frac{(p_0 x_0 \cdot N)}{m_0}, \frac{(p_0 + x_0)}{m_0}; \frac{\left(x_0^2 - N\right)}{m_0}\right)$$

which is a genuine triple due to our congruence condition on x_0. If we note that $x_0^2 - N = m_0 m_1$, we may see that keeping $N - x_0^2$ "small" helps to keep also m_1 "small". The next step in the *cakravāla* is to find x_1 in $\mathbf{Z}$ so as to enable us to obtain the composite $(p_1, q_1; m_1)\left(x_1, 1; x_1^2 - N\right)$ is a genuine triple to be defined as $(p_2, q_2; m_2)$. Actually x_1 is to satisfy the congruence $q_1 x_1 \equiv -p_1 (\mathrm{mod}\ m_1)$ as well as the condition that $x_1^2 - N$ is "small" (i.e. least in absolute value among possibilities for x_1 got by using *kuttaka*. Having got the triple $(p_2, q_2; m_2)$, one proceeds to find suitable x_1 (modulo m_2) to move on to a triple $(p_3, q_3; m_3)$ and eventually, as mentioned above to a solution of (Eq. 2).

Example. For $N = 31$, we have $p_0 = 6, q_0 = 1$, $m_0 = 5$ giving us (in the terminology of Bhaskara) the (corresponding) auxiliary equation $31 \times 1^2 + 5 = 6^2$. Then by Bhaskara's lemma (i.e. indeed composing (6, 1; 5) with $\left(x_0, 1; x_0^2 - 31\right)$ so that $x_0 \equiv -6$ (mod 5) and further the absolute value of $x_0^2 - 31$ is least (among all integers x_0 congruent to −6 modulo 5), we obtain $x_0 = 4$ and $(p_1, q_1; m_1) = (6, 1; 5)(4, 1, -15) = (11, 2; -3)$. Next with the auxiliary equation $31 \times 2^2 - 3 = 11^2$, *kuttaka* is used to find x_1 with $2x_1 \equiv -11 (\mathrm{mod}\ 3)$ and $x_1^2 - 31$ least (in absolute value), yielding

$x_1 = 5$ and $(p_2, q_2; m_2) := (p_1, q_1; m_1)(5, 1; -6) = (-39, -7; 2)$. Since $m_2 = 2$, a shortcut via the *bhavana* is to define directly $(p_3, q_3; m_3) := (-39, -7; 2)(-39, -7; 2) = (-1{,}520, -273; 1)$, solving $x^2 - 31y^2 = 1$ at once. On the other hand, one could follow the general method indicated in the preceding paragraph to get $x_2 = 5$ and the triples $(-39, -7; 2)(5, 1, -6) = (-206, -37; -3)$, $(-657, -119; 5), (-1{,}520, -273; 1)$ in that order. Further iteration of the method not only yields more and more solutions for $s^2 - 31y^2 = 1$ but also reveals a "cyclic" pattern in the *additives* m_i (vindicating the chosen name *cakravāla*). Using familiar notation for periodic simple continued fractions for quadratic irrationalities (e.g. Davenport 1990, pp. 104–105), we write $\sqrt{31} = \langle 5\overline{1,1,3,5,3,1,1,10}\rangle$ and the relevant *convergent* $\langle 5, 1, 1, 3, 5, 3, s1, 1\rangle = 1520/273$ got by omitting the *partial quotient* 10 from the *very* first period $\overline{1,1,3,5,3,1,1,10}$ gives the same solution for (Eq. 2) as above. Weil's own version of the *cakravāla* has the merit of not only totally dispensing with the use of *kuttaka* (in Bhaskara's exposition of the *cakravāla*) but also making the "cyclic" pattern in the occurrence of the *additives* m_i quite transparent and *in tune with* the phenomenon of *periodicity* in the continued fraction expansion for $\sqrt{N}$. Are not the triples (1,766,319,049, 226,153,980; 1) for $N = 61$ and (48,842, 5,967; 1) for $N = 67$ discovered and offered to us by Brahmagupta and Bhaskara masterpieces adorning the lustrous history of *cakravāla*?

To be fair though, one should recall Weil's remarks that a rigorous treatment as explained above for constructing the successive triples (p_i, q_i; m_i) "may have been known to Indian mathematicians only experimentally and there is nothing to indicate whether they had proof for them, or even part of them" and again that "For the Indians, of course, the effectiveness of *cakravāla* could be no more than an experimental fact, based on their treatment of a great many special cases, some of them of considerable complexity and involving (to their delight, no doubt) quite large numbers. Fermat was the first to perceive the need for a general proof and Lagrange the first to publish one. Nevertheless, to have developed the *cakravāla* and to have applied it successfully to such difficult cases as $N = 61$ or $N = 67$ had been no mean achievement". Weil is unsparing as well in his critical analysis of Euler's contribution to the topic of "Pell's equation" in the form of drawing attention to the periodicity and "palindromic" property of the "partial quotients" in the continued fraction expansion for $\sqrt{N}$ or their use in solving "Pell's equation" with perhaps merely experimental evidence to back up his assertions. Although the "Cattle Problem of Archimedes" (Davenport 1990) is usually associated with Pell's equation, one learns from Weil that equations such as (Eq. 2) "do occur in Diophantus. . ., but it is a rational solution that is asked for, even when accidentally a solution in integers is obtained. . .". A detailed discussion of Kronecker's interesting solution (using elliptic functions) for Pell's equation can be found in Siegel's section 27.1 (1963).

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Calculus

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The Indian origin of infinite series, found in widely distributed texts, has long been publicly known to Western scholars (Whish, 1832).

Recent research (Raju, 2007) has shown that these Indian developments really did amount to the calculus. (This brings to the forefront various epistemological issues, and the very philosophy of mathematics taken for granted in Western discourse.) This research has also pushed the historical origin of the calculus in India much further back to the fifth century CE Āryabhaṭa and his method of obtaining sine values by numerically solving the corresponding differential equation using a finite difference technique.

The infinite series had originated in India by the fourteenth century. An explicit formula for the sum of an infinite (*anantya*) geometric series is given by the fifteenth and sixteenth centuries Nīlakantha in his *Āryabhaṭīyabhāṣya* (Sastri 1930, commentary on *Gaṇita* 17, p. 142.)

एवं यस्तुल्यच्छेदपरभागपरम्पराया अनन्ताया अपि संयोगः तस्यानन्तानामपि कल्प्यमानस्य योगस्याद्यावयविनः परम्परांशच्छेदादेकोनच्छेदांशसाम्यं सर्वत्रापि समानमेव।

which may be translated (cf. Sarma, 1972, p. 17):

> The sum of an infinite [*anantya*] series, whose later terms (after the first) are got by dividing the preceding one by the same divisor everywhere, is equal to the first term multiplied by the common divisor and divided by one less than the common divisor.

That is $a + \frac{a}{d} + \frac{a}{d^2} + \cdots = \frac{ad}{d-1}$. (It is assumed that the divisor $d > 1$, so that the common ratio is less than 1.) This is obviously the earliest textual source in the world for a formula for a properly infinite sum.

Was this infinite sum based on a "rigorous" notion of limits? In fact, it was based on something superior. Indian mathematicians used a different number system involving what would today be called "non-Archimedean" arithmetic *and* a different epistemology, which allowed discarding of infinitesimals (see also "► Zeroism").

In terms of formal mathematics, the Indian approach may be understood as follows. Ever since algebra began (with Brahmagupta), Indian mathematicians referred to polynomials as "unexpressed (*avyakta*) numbers." This led naturally to "unexpressed fractions," or what formal mathematicians would today call the non-Archimedean ordered field of rational functions. (For an elementary construction of this field, see Moise, 1968, Appendix.)

A non-Archimedean field contains a number x such that $x > n$ for every integer n. Such a number may be called infinite. Being a field, it also contains the multiplicative inverse of the number which satisfies $0 < \frac{1}{x} < \frac{1}{n}$ for every integer n, so that $\frac{1}{x}$ may be called infinitesimal. The existence of infinitesimals means that limits are not unique, and one must discard infinitesimals. ("Infinitesimal" does *not* mean the same thing as "imperceptible" or "intangible," e.g., $\frac{3}{n}$ or $\frac{n}{n^2}$ are infinitesimals.) The traditional Indian process of summing infinite series by discarding of infinitesimals, as used in deriving the above formula, is equivalent to limits by order counting (Raju, 2007, Chapter 3).

Discarding infinitesimals is related to discarding small numbers, but clearly goes a step beyond it. Small numbers were traditionally discarded, from at least 2,500 years ago, since the days of the *śulba sūtra* to provide "approximate" values of $\sqrt{2}$, π, etc. The terms then used were *saviśeṣa* (with something remaining) (Baudhāyana *śulba sūtra*, 2.12 l, Sen & Bag, 1983, p. 169), *anitya* (impermanent) (Apastamba *śulba sūtra*, 3.2, Sen & Bag) in the *śulba sūtra*, and *āsanna* (near value) by Āryabhaṭa (Gaṇita, 10, Shukla & Sarma, 1976). This was similar (but not identical) to the way one today has no choice but to discard small numbers in computer (floating point) arithmetic, since a computer cannot physically implement formal "real" numbers obtained as metaphysical limits.

Further, since Āryabhaṭa (fifth century), at least, an algorithm was available for square root extraction, so there was a recursive process of generating an infinite series for, say, $\sqrt{2}$. A recursive series for difficult fractions, similar to continued fractions, was also used since Brahmagupta. (For full details, and for the use of this fraction-series expansion in developing later-day infinite series, see Raju, 2007, Chapter 3.) Summing an infinite series, as Nīlakaṇṭha did, by discarding infinitesimals, or

order counting, clearly goes beyond the much older process of discarding small quantities by truncation of infinite series or halting those recursive procedures after a finite number of steps.

Further, one should not just assume that metaphysical limits or Western metaphysical ways of handling infinity are automatically superior. Thus, the use of non-Archimedean arithmetic (plus zeroism) leads to a notion of derivative superior to the present-day college-text definitions of the derivative as a limit, for the college-text definition fails with a discrete number system like floating point numbers on a computer, or with discontinuous functions. While the Schwartz theory does allow a discontinuous function to be differentiated, Schwartz distributions cannot be readily multiplied; therefore, that notion of derivative cannot be used for nonlinear differential equations of physics (Raju, 1989).

The whole problem of how to define the derivative or the notion of probability has a natural and very simple resolution using Indian "non-Archimedean" arithmetic and the related philosophy of zeroism, a solution which is better and far simpler than the resolution using nonstandard analysis, as was used earlier (Raju, 2007, Appendix).

Further, it is clearly wrong to assume that the dominant philosophy of formalism, even though globalized by colonialism, represents a universal philosophy of mathematics or is the only correct way to do mathematics. Even the logic underlying mathematical proofs is not universal (Raju, 2001; see also article on "▶ Logic"). Formalist philosophy hence involves a biased metaphysics (Raju, 2011b).

Calculus can also be taught with a different philosophy which follows its actual historical development and makes it easy to learn. (Thus, over the last few years, "decolonized" courses on "calculus without limits" have been taught with significant success to eight groups in four universities in three countries; Raju, 2011c, 2012.)

Indian mathematicians long knew about *finite* geometric series, which they called *guṇottara saṅkalitā* or *guṇottara śreḍhī* (multiplicative series), and methods of summing the finite geometric series were a part of the elementary school curriculum from at least 1,300 years ago and are found in numerous elementary texts such as the *Pāṭi Gaṇita* of Śrīdhara (Śrīdhara, Shukla, 1959, trans. p. 75.) Indeed, summing a finite multiplicative series was a very common commercial problem found in a variety of other sources such as the *Gaṇita Sāra Saṁgraha* of Mahāvīra (Jain, 1963), *Mahā Siddhānta* of Āryabhaṭa II (Dwivedi, 1900), the *Līlāvatī* of Bhaskara II, etc. (rule 126 et. seq; the numbering differs between Colebrooke, 1816 and the critical edition of Sarma, 1975).

In fact, the place value system lends itself naturally to "geometric" (multiplicative) series, and the first such series is found thousands of years earlier in the Yajurveda (17.2), and in the Lalita Vistara Sutra (Chapter 12) where it goes up to large numbers like 10^{53} (named *tallakṣaṇa*).

Of what use were these infinite series? An infinite series expansion for the sine and cosine (today called the "Taylor" series, after a pupil of Newton) was used by Madhava of Sangamagrama (1340 CE) to calculate precise sine and cosine values, by truncating the series to 11th- and 12th-order polynomials. The infinite series expansion is found in two verses stated in various texts, such as the *Tantrasaṅgraha Vyākhyā*/*Yuktidīpikā* (2.440 – 443) (Sarma, 1977).

निहत्य चापवर्गेण चापं तत्तत्फलानि च ।
हरेत् समूल्युग्वर्गैस्त्रिज्यावर्गहतैः क्रमात् ॥ ४४० ॥
चापं फलानि चाधोऽधो न्यस्योपर्युपरित्यजेत् ।
जीवाप्त्यै, संग्रहोऽस्यैव विद्वान् इत्यदिना कृतः ॥ ४४१ ॥

This verse may be translated:

> Multiply the arc by the square of the arc, and take the result of repeating that [any number of times]. Divide [each of the above numerators] by the squares of successive even numbers increased by that number [lit. the root] and multiplied by the square of the radius. Place the arc and the successive results so obtained one below the other, and subtract each from the one above. These together give the *jīvā*, as collected together in the verse beginning with *"vidvān"* etc.

In present-day mathematical terminology, the above passage says the following. Let r denote the radius of the circle, let s denote the arc, and let t_n denote the nth expression obtained by applying

the rule cited above. The rule requires us to calculate as follows.

1. Numerator: multiply the arc s by its square s^2, this multiplication being repeated n times to obtain $s \cdot \prod_1^n s^2$.
2. Denominator: multiply the square of the radius, r^2, by $[(2\,k)^2 + 2\,\mathrm{k}]$ ("the squares of successive even numbers increased by that number") for successive values of k, repeating this product n times to obtain $\prod_{k=1}^{n} r^2\left[(2k)^2 + 2k\right]$.

Thus, the nth iterate is obtained by

$$t_n = \frac{s^{2n} \cdot s}{(2^2+2)\cdot(4^2+4)\cdot \quad \cdots \quad \cdot\left[(2n)^2+2n\right]\cdot r^{2n}}. \tag{1}$$

The rule further says

$$\text{jīvā} = s - t_1 + t_2 - t_3 + t_4 - t_5 + \cdots \tag{2}$$

$$= s - \frac{s^3}{r^2\cdot\left(2^2+2\right)} + \frac{s^5}{r^4\left(2^2+2\right)\ \left(4^2+4\right)} - \cdots. \tag{3}$$

Substituting

(1) $\text{jīvā} \equiv \mathrm{r}\sin\theta$,
(2) $s = r\ \theta$, so that $s^{2n+1}/r^{2n} = r\ \theta^{2n+1}$, and noticing that
(3) $\left[(2k)^2+2k\right] = 2k\cdot(2k+1)$, so that
(4) $(2^2+2)\ \ (4^2+4)\cdots\left[(2n)^2+2n\right] = (2n+1)!$, and cancelling r from both sides, we see that this is entirely equivalent to the well-known infinite series

$$\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \cdots. \tag{4}$$

A similar rule gives another infinite series for *śara*, corresponding to the infinite series for cosine. A similar series was available for the inverse arctangent function, and various other infinite series were developed in the process of accelerating convergence of these series (Raju, 2007, Chapter 3).

The above infinite series was used to devise a numerically efficient formula (Raju, 2007, Chapter 3) which finally leads to the table of 24 sine values accurate to the third sexagesimal minute (*tatparā*) and stated in reverse-sexagesimal *kaṭapayādi* notation. (For a detailed explanation of this *kaṭapayādi* system and the precise accuracy of the values, see Raju, Chapter 3.) The first few and last few lines of the verse are as follows

श्रेष्ठ नाम वरिष्ठाना हिमाद्रिर्वेदभावनः।
तपनो भानुसूक्तज्ञो मध्यमं विद्धि दोहनम्॥
धिगाज्यो नाशनं कष्टं छन्नभोगाशयाम्बिका।
म्रिगाहारो नरेशोऽयं वीरो रणाजयोत्सुकः॥
...
छायालयो गजो नीलो निर्मलो नास्ति सत्कुले।
रात्रौ दर्पणामभ्राङ्गं नागस्तुङ्गनखो बली॥

धीरो युवा कथालोलः पूज्यो नारीजनैर्भगः।
कन्यागारे नागवल्ली देवो विश्वस्थली भृगुः॥
तत्परादिकलान्तास्तु महाज्या माधवोदिताः।
स्वस्वपूर्वविशुद्धे तु शिष्टास्तत्खण्डमौर्विकाः॥ २.९.५॥

This corresponds to the values in Table 1.

The accuracy of these values in decimals is given in Table 2.

The actual calculation requires the value of the number today called π. Madhava had obtained the value accurate to 12 decimal places. This was obtained by accelerating the convergence of various slowly convergent series such as the infinite series today wrongly called "Leibniz series." Nīlakaṇṭha, in his *Āryabhaṭīya Bhaṣya*, in his commentary on *Gaṇita* 10 (Sastri, 1930, p. 56), described the subtle value of π given by Madhava of Sangamagrama as follows:

सङ्गमग्रामजो माधवः पुनरत्यासन्नां परिधिसंख्यामुक्तवान् –

विबुधनेत्रगजाहिहुताशनत्रिगुणवेदभवारणबाहवः।
नवनिखर्वमिते वृतिविस्तरे परिधिमानमिदं जगदुर्बुधाः॥

The numbers in this verse are according to the old *bhūta saṁkhyā* system, which uses word

Calculus, Table 1 Madhava's sine values

No.	Kaṭapayādi	kalā (′)	vikalā(″)	tatparā(‴)
1	श्रेष्ठं नाम वरिष्ठानां	224	50	22
2	हिमाद्रिर्वेदभावनः	448	42	58
3	तपनो भानुसूक्तज्ञो	670	40	16
4	मध्यमं विद्धि दोहनम्	889	45	15
...	...	...	...	...
21	धीरो युवा कथालोलः	3,371	41	29
22	पूज्यो नारीजनैर्भगः	3408	20	11
23	कन्यागारे नागवल्ली	3,430	23	11
24	देवो विश्वस्थली भृगुः	3,437	44	48

Calculus, Table 2 Accuracy of Madhava's sine table

No.	Mādhava's sine value	Difference
1	0.0654031452	0.0000000160
2	0.1305262297	0.0000000375
3	0.1950903240	0.0000000020
4	0.2588190035	−0.0000000416
...	...	...
...	...	...
21	0.9807852980	0.0000000176
22	0.9914448967	0.0000000353
23	0.9978589819	0.0000000587
24	1.0000000000	0.0000000000

numerals. Thus, *netra* means 2 because one has two eyes, *veda* = 4, *guṇa* = 3, *tri* = 3, etc. (For more details about the *bhūta saṁkhyā* system, see Datta & Singh, 1935.) The quantity *nikharva* = 10^{11}. Thus, the above verse may be translated:

> Mādhava of Saṅgamagrāma spoke the approximate [*āsanna*] number of the circumference of a circle: *vibudha* [33] *netra* [2] *gaja* [8] *ahi* [8] *hutāśana* [3] *tri* [3] *guṇa* [3] *veda* [4] *bhavāraṇa* [27] *bāhavaḥ* [28], i.e., [2,827,433,388,233] is the measure of a circle of diameter *nava* [9] *nikharva* [100,000,000,000].

This corresponds to π = 3.141,592,653,5922 ..., accurate to 11 places after the decimal point, with the 12th and 13th places (92 respectively) differing slightly from their accurate value (89). The term *nikharva* continues the series, *koṭi*, *arbuda*, *abja*, *kharva*, *nikharva*, then in common use for centuries. (*Pāṭī Gaṇita*, 7. Shukla, 1959.) Parts of this series coming from Vedic times are still in current use, e.g., *koṭi* = crore. (Currently, an *arbuda*, called "arab," is 100 crores, while a *kharva*, called "kharab," is 100 arabs.) The more common expression for π stated in the *kaṭapayādi* system, using reverse-sexagesimal notation, gives the radius of a circle with circumference 21,600 (= number of minutes in 360°) as *Devo viśvasthalī bhṛguḥ*, corresponding (in reverse order) to 34374448 or 3437′ 44″ 48‴, which is

substantially more accurate than the seventh-century Bhāskara's figure of 3438′, or the ninth-century Vateśvara's figure of 3437′ 44″.

As is clear from the above figures, these methods developed gradually over a thousand years, as the requirements of precision gradually increased. These accurate trigonometric values were needed for astronomy used for the practical needs of the calendar and navigation. The calendar was needed for successful monsoon-driven agriculture, in India, while navigation was needed for overseas trade. The whole tradition of computing 24 sine and cosine values, 3.75° apart, was started a thousand years earlier by Āryabhaṭa in the fifth century. He computed 24 sine values and the value of π accurate to the first sexagesimal minute (*kalā*, about 5 decimal places). It is well known that Āryabhata's value of π was quoted by al Khwārizmī, but not so well known that this was still being repeated by sixteenth-century European navigational theorists, such as Simon Stevin (Pannenkoek & Crone, 1961).

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Calculus Transmission

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It has gone unnoticed that Āryabhaṭa's 24 sine values (see "▶ Calculus") involved a striking departure from the earlier geometric tradition and a paradigm shift to numerical techniques. The geometric tradition is useful only in simple situations where high symmetry is present. It cannot be used to calculate the sine of 1° but was earlier used to compute 6 sine values 15° apart.

In a second radical departure, Āryabhaṭa used difference equations, instead of algebraic equations. Indeed, in the tenth *gītikā* (this is called the tenth *gītikā* since the first two are invocations; Shukla & Sarma, 1976), of the *daśgītikā* section, he states only the sine *differences*:

मखि भखि फखि धखि णखि ञखि
ङखि हस्झ स्ककि किष्घ श्घकि किघ्व ।
घ्लकि किग्र ह्क्य धकि किच
स्ग श्झ ङ्व क्ल प्त फ छ कलार्धज्या ॥ १२॥

The numbers involved here are expressed in Āryabhaṭa's novel numerical notation (see Shukla & Sarma, 1976 or Raju, 2007, Chap. 3). Thus, the verse may be translated:

> 225, 224, 222, 219, 215, 210, 205, 199, 191, 183, 174, 164, 154, 143, 131, 119, 106, 93, 79, 65, 51, 37, 22, 7—[these are the] sine [lit. half-chord] differences [for the quadrant divided into as many equal parts, each part hence being 225′] [in] minutes.

The method of calculating these differences is explained in Gaṇita 12 as:

प्रथमाच्चापज्यार्धाद्यैरूनं खण्डितं द्वितियार्धम् ।
तत्प्रथमज्यार्धांशैस्तैस्तैरूनानि शेषाणि ॥ १२॥

This may be translated:

> (12) The sine of the first arc divided by itself and diminished gives the second sine difference. That same first sine, when it divides successive sines gives the remaining [sine differences]. (Trans. by the author, based on the Hindi translation of Rai, 1976, pp. 42–43; cf. Shukla & Sarma, 1976, p. 51)

That is, if the quadrant of the circle is divided into, say, 24 equal parts, where $R_1, R_2, \ldots, R_{24}$ are the 24 corresponding sine values; δ_1 $(= R_1)$, $\delta_2, \ldots, \delta_{24}$ are the corresponding sine differences; and $\delta_i = R_i - R_{i-1}$, for $i \geq 2$, then Āryabhaṭa's rule consists of the following two parts:

$$\delta_2 - \delta_1 = -\frac{R_1}{R_1}, \tag{1}$$

$$\delta_{n+1} - \delta_n = -\frac{R_n}{R_1}. \tag{2}$$

This cannot be understood as an algebraic equation, since that would lead to the wrong answers. More precisely, it can be regarded as an algebraic equation for calculating the second difference but not for its proper purpose, which is to calculate sine differences (Raju, 2007).

Āryabhaṭa's technique of solving those difference equations was later modified by Nīlakaṇṭha to make it accurate to thirds. Thus, the above interpretation is also the one given by Nīlakaṇṭha in his *Āryabhaṭīyabhāṣya* (Sastri, 1930), except that Nīlakaṇṭha makes it more precise, by stating it in the form

$$\delta_n^{(2)} = -\left(\frac{R_n}{R_1}\right)\ (\delta_1 - \delta_2). \tag{3}$$

The difference here is that for Āryabhaṭa, working to the precision of minutes, $\delta_1 - \delta_2 = 225–224 = 1$, while this is no longer the case with Nīlakaṇṭha, working to the precision of thirds, who uses the values, $R_1 = [224; 50; 22]$ and $R_2 = [448; 42; 58]$, so that $\delta_2 = [223; 52; 36]$ and $\delta_1 - \delta_2 = [0; 57; 46]$.

Āryabhaṭa's method of solving differential equations by finite differences is today wrongly called "Euler's method" after Euler who studied the relevant Indian texts when he wrote an article on the Indian calendar in 1700. Further, the numerical solution of differential equations (rather than metaphysical existence and

uniqueness theorems) is at the heart of all practical applications of the calculus even today.

Āryabhaṭa's process of setting up and solving differential equations involves only the simple "rule of 3" or what would geometrically be called linear interpolation. However, unlike the geometric notion, the arithmetic process easily extends recursively, and recursive application of this process naturally leads to second- and higher-order differences and thence to the infinite series used by Madhava and others.

Note that Āryabhaṭa himself brought in the *second* difference. Today, we would rewrite the formula as

$$\delta_n^{(2)} \equiv \delta_{n+1} - \delta_n = -\frac{R_n}{R_1}, \tag{4}$$

corresponding to the idea that the second difference/derivative of the sine is proportional to the sine itself. But with finite differences, a little more detail is necessary, and Āryabhaṭa also specifies the constant of proportionality.

Second differences were also used for interpolation, from Brahmagupta onwards, about a century later, and this use was continued subsequently by Vaṭeśvara and Bhāskara II.

Brahmagupta's second-order interpolation formula, nowadays wrongly called "Stirling's formula," is stated as follows (*Uttarakhaṇḍakhādyaka*, II.1.4, Chatterjee, 1970, vol. II, p. 177).

गतभोग्यखण्डकान्तरदलविकल वधाच्छतैर्नवभिराप्त्या।
तद्युतिदलं युतोनं भोग्यादूनाधिकं भोग्यम्॥ ४॥

This has been translated (using Bhaṭṭotpala's tenth century CE [Saka 888] commentary) as:

> Multiply the *Vikalā* by half the difference of the *Gatakhaṇḍa* and the *Bhogyakhaṇḍa* and divide the product by 900. Add the results to half the sum of the *Gatakhaṇḍa* and the *Bhogyakhaṇḍa*, if their half sum is less than the *Bhogyakhaṇḍa*; subtract, if greater. [The result in each case is the *Sphuṭabhogyakhaṇḍa* or correct "tabular" difference.]

Here, the underlying table is that calculated for *khaṇḍajyā*-s or sine differences for intervals that are spaced h apart, where it is assumed that $h = 15^\circ$ or $900'$. The *gatakhaṇḍa* or "past difference" ($= \delta_n$) refers to the interval that has been crossed, and the *vikalā* ($= \theta$) is the amount in minutes by which it has been crossed at the point at which we want to interpolate. The *bhogyakhaṇḍa* ($= \delta_{n+1}$) is the one yet to come. Thus, the formula states:

$$\text{Sphuṭabhogyakhaṇḍa} = \frac{\delta_n + \delta_{n+1}}{2} \pm \frac{\theta}{h} \ \frac{\delta_n - \delta_{n+1}}{2} \tag{5}$$

$$\sin(nh+\theta) - \sin nh = \frac{\theta}{h} \times \text{sphuṭabhogyakhaṇḍa}. \tag{6}$$

This amounts to

$$\sin(nh+\theta) = \sin nh + \frac{\theta}{h} \ \frac{\delta_n + \delta_{n+1}}{2} \pm \frac{\theta^2}{h^2} \ \frac{\delta_n - \delta_{n+1}}{2}. \tag{7}$$

Vaṭeśvara (Siddhānta, II.1.63 – 82) (in 904 CE) uses backward differences, works with arcs that are only $56'\ 15''$ apart, and still uses quadratic interpolation, explicitly giving the second of the above formulae, among many others (Shukla, 1976, part I, p. 96, and part II, p. xlvi). This enabled him to improve Āryabhaṭa's sine values (accurate to the minute) and achieve accuracy to seconds.

Bhāskara II, while offering a justification for these formulae stated by Vaṭeśvara, brings in the present or instantaneous sine difference as the mean value of the past and future sine difference. This concept of *tātkālika bhogya khaṇḍa* or instantaneous difference leads him naturally to the concept of *tātkālika gati* or *instantaneous velocity* of a planet, since it is in that context of planetary motion that these interpolations were typically required (*Siddhānta Śiromaṇi*, *Spaṣṭādhikāra* 36–38, and accompanying autocommentary *Vāsanābhāṣya*, Sastri, 1858, 1929, 1939, 1943; Sengupta, 1932). This notion of derivative used for planetary velocity (*gati*) is not a "precursor" to the Newtonian notion, using

fluxions, but involves an understanding of the derivative which is superior from both a practical and an epistemological perspective, as explained earlier.

The calculus in India was also used to derive accurate formulae for areas and volume – a typical application of present-day integral calculus. The volume of a sphere was first correctly expressed by Śrīdhara in his *Triśaṭikā* (Dwivedi, 1899; Ramanujachari and Kaye 1912).

Bhāskara II suggests a very interesting pedagogical demonstration, involving a model of the earth made of clay or wood.

He concludes:

> This is as I have said in my Arithmetic: (*Lilāvatī*, rule 201; Sarma, 1975) the area of a circle is equal to the product of the circumference by one-fourth of the diameter [πr^2]. That result multiplied by 4 gives the surface of the sphere [$4\pi r^2$], which is like the net surrounding a hand ball; the same (surface of a sphere) when multiplied by the diameter and divided by six $\left[\frac{4}{3}\pi r^3\right]$ becomes invariably the volume of the sphere.

These correct formulae for the surface area and volume of a sphere are significant, since the correct formulae for the volume of a sphere were not known earlier.

The term "Kerala school," used by the late K. V. Sarma, has been misused to suggest that calculus originated solely in Kerala. As we have seen, the whole technique of numerically solving differential equations began with Āryabhaṭa who did this work in Kusumpura or Patna. K. V. Sarma, himself, denied that Āryabhaṭa was somehow from Kerala (Sarma, 2001). Further, as the title of Nīlakaṇṭha's *Āryabhaṭīyabhāṣya* says, Nīlakaṇṭha regarded himself as belonging to the Āryabhaṭa school. This is also significant since Nīlakaṇṭha, as his name "somasūtvan" says, was a Brahmin of the highest caste, while Āryabhaṭa, as his name "bhaṭa" indicates, belonged to a low caste. ("Bhaṭa" meaning slave should not be confounded with "bhaṭṭa" which is the appellation of a learned Brahmin.) The Āryabhaṭa school in Kerala clearly shows that neither the caste divide nor the regional divide was as strong then. The development initiated by Āryabhaṭa was continued by a variety of other mathematicians, from Gujarat, Ujjain, and Banaras. The first infinite/indefinite series was derived by Brahmagupta, as a technique for approximating difficult fractions, in what this author has called the "fraction series expansion" (*Brāhma Sphuṭa Siddhānta* 12.57, more details in Raju, 2007, Chap. 3).

Even more importantly, a key input in the summation of the series was a general formula given by Nārāyaṇa Paṇḍit of Benares in his *Gaṇita Kaumudi* (Dwivedi, 1942, p. 123) for the *vārasaṅkalitā*. (Since Nārāyaṇa is a very common name in India, some scholars have confounded Nārāyaṇa Paṇḍit with some other Nārāyaṇa in the Kerala school.) This *vārasaṅkalitā* series, involving summation of partial sums, is also mentioned by Bhaskara II, who, however, does not give a general formula for summing it. Some five centuries before Mādhava, Govindasvāmin (ca. 800, *Bhāṣya* on the *Mahā Bhaskarīya*, iv.22; Sen, 1966, p. 78) and then Udayadivākara (tenth century, *Sundarī* on the *Laghu Bhāskarīya*, ii.3 − 6; Sen, p. 280), of the Āryabhaṭa school in Kerala, tried to obtain trigonometric values accurate to the thirds (i.e., third sexagesimal minute), but their values were not accurate enough; Mādhava's trigonometric values *are* however accurate to the thirds. Hence, it is clear that a key input enabling the computation to thirds is the expression for the sum of the *vārasankalitā* given by Nārāyaṇa Paṇḍit of Benares in his *Gaṇita Kaumudi*. Thus, there is no way that the calculus developments can be localized to any one region or caste in India.

What was the social and practical need for such highly accurate sine values? This is related to the two key sources of wealth in India, namely, agriculture and overseas trade. (For a summary account, see GJH, 2007.) Since agriculture in India was (and still is) mostly monsoon driven, it required a good calendar to get the right time of the monsoons, described in the Indian lunisolar calendar by the months of *sawan* and *bhadon*. There is no such possibility in the Gregorian calendar. The Indian calendar was based on a sophisticated astronomical model, similar, but not identical, to the one attributed to the supposed Greek author of the *Almagest* (Raju, 2014).

In this context, some authors refer to the sine as Rsine and claim that trigonometry was transmitted to Indians from the *Almagest*. However, the actual evidence tells us that trigonometry was transmitted from India to Europe via Arabs. Indeed, the very word "sine" derives from a translation howler during the Toledo mass translations of Arabic texts in 1125 CE. The word derives from the Latin *sinus* or fold, which is a translation of the Arabic *jaib*, meaning pocket, which is a wrong reading of the Arabic *jiba*, from the vernacular *jīvā*, for the Sanskrit *jyā*, meaning chord (as used by Āryabhaṭa).

Indeed, scientific texts are accretive, so that the twelfth-century *Almagest* reflects twelfth-century knowledge which came about by transmission from India. There is no serious evidence for either its existence in its present form in the second century CE or that its author was a Roman-Greek called Claudius Ptolemy. The failure to reform the Julian calendar since the fifth century is counterevidence against this belief (Raju, 2010).

The linguistic error of translation in the term "sine" was accompanied by a conceptual error, as in the very word "trigonometry" where the functions relate to the circle, not the triangle. That error persists to this day in the teaching of "trigonometry" which is stuck in the pre-Āryabhaṭa era. The word "trigonometry" is in quotes, since this geometric method wrongly suggests that the concepts of sine and cosine relate to the triangle, whereas they actually relate to the circle.

Studying the movements of planets on the celestial sphere naturally required calculations with the circular functions sine and cosine. Hence, sine tables are commonly found in Indian astronomy and mathematics texts, starting from the third-century CE *Sūrya Siddhānta*. This requirement of an accurate calendar for successful agriculture still persists. (Specifically, on a number of occasions in the last decade, there has been large-scale crop failure due to mistimed agricultural operations; Raju, 2007, Chap. 4.)

Accurate sine values (and an accurate calendar) were also required for navigation even to determine latitude. At night, latitude could be determined simply by measuring the altitude of the pole star. This was done using a sophisticated instrument (with harmonic interpolation) which was never earlier understood by Western historians (Raju, 2007, Chap. 5). This instrument was used by the Indian navigator who brought Vasco da Gama to Calicut in India from Melinde in Africa. However, Vasco neither knew nor immediately understood the method. Since the Malayalam word for the pole star (*kau*) also means teeth and the instrument used by the navigator is held between the teeth, Vasco da Gama recorded that "the pilot told the distance by his teeth"!

In daytime, latitude was determined from observations of solar altitude at noon, and longitude was determined by solving the appropriate longitude triangles (Raju, 2007, Chap. 4). A solution to these two problems of latitude and longitude determination is found in many early Indian texts, such as the text of the seventh-century Bhaskara I, a commentator on the fifth-century CE Āryabhaṭa.

The seventh-century Bhaskara I explains (*Laghu Bhāskarīya*, III.2-3, Shukla, 1963, p. 42; Raju, 2007, Chap. 4) how to calculate the local latitude (ϕ) from the equinoctial midday shadow (s) using a gnomon of height g using the formula $\tan\phi = \frac{s}{g}$. Note that this formula is useful only if one has a method of computing the arctangent function (or a method of "arcifying" sines), and this explains the need for the infinite series for the arctangent.

The seventh-century Bhaskara I also explains (*Laghu Bhāskarīya*, III.22 − 23) how to calculate the local latitude from the observation of solar altitude at noon, provided also that the solar declination is known. That requires a good calendar which correctly tells the date of the equinox.

Bhaskara I also gives a method of longitude determination, by solving a longitude triangle, from a knowledge of the departure or distance between two points A and B, and the corresponding difference of latitude (*Mahā Bhāskarīya* II.3 − 4, Shukla, 1960, pp. 49–50). He himself criticized the rule, among other reasons, for neglecting the sphericity of the earth and not using spherical triangles.

This solution of the longitude problem required an accurate knowledge of the size of the earth. Columbus underestimated the size of the earth by about 40 %, and the resulting navigational disasters led to the Portuguese ban of 1500 on carrying globes aboard ships. In contrast, most Indian mathematics and astronomy texts also state an estimate of the radius of the earth. This is stated in *yojanas*, and we do not know *exactly* how much a yojana was. Nevertheless, we do know that al Biruni came to India, studied astronomy, and reported on Indian astronomy in his tenth-century *Kitab al Hind*. His estimate was stated in Arabic miles and intended to corroborate Khalifa al Mamun's direct measurement of 1° of arc in the desert. This method of calculating the size of the earth (Raju, 2007, Chap. 4) required very accurate sine and cosine values, and it is also the method implicit in the definition of the Arabic *zam* (from the Sanskrit *yāma*), as the "distance from here to the horizon" (Raju, Chap. 5). Al Biruni's error was 0.25 %, compared to the error of 40 % in Columbus' estimate and the error of 25 % in Newton's first estimate (Rizvi, 1979).

Further, in contrast to Indo-Arabic techniques of celestial navigation, the European technique of navigation involved charts. Hence, apart from the issue of latitude and longitude at sea, a key problem of European navigation was that of loxodromes: because a chart is flat while the surface of the earth is curved, holding a straight course in one direction (using a magnetic compass or a straight line joining two stars) does not result in a straight line on the surface of the earth but a curved line, called a loxodrome. The solution to this problem of loxodromes was provided by the Mercator chart which used an old projection technique of Chinese (Dunhuang) star charts (Needham, 1981, pp. 123–124) to map loxodromes to straight lines. Constructing the Mercator chart required an accurate table of secants or, equivalently, accurate sine values. (The formulae for the Mercator projection are widely available; see, e.g., Raju, 2007, p. 339.) An accurate technique of navigation was the biggest scientific challenge in Europe then. Hence, the Jesuits in Cochin were naturally interested in these Indian texts with accurate sine values. Their college in Cochin helped procure and translate local Indian texts and sent them back to Europe in a repeat of the Toledo model of mass translation of books. In place of the Mozarabs of Toledo, they then had the support of the local Syrian Christian community in the vicinity of Cochin.

The translated Indian texts would naturally have gone first to the Jesuit general. There is ample circumstantial evidence that did happen. Christopher Clavius, who authored the Gregorian calendar reform, also published in his name a table of sines in 1607. Curiously, these were the so-called Rsines, in that they explicitly involved the radius of the circle. Simon Stevin follows the same practice for his secant tables. Curiously, Clavius used the same large number for the radius as used in Madhava's values (Clavii, 1607). Documentary evidence of a connection comes from Clavius' student Matteo Ricci who visited Cochin just prior to the Gregorian reform to get information about Indian methods of timekeeping (Ricci, 1581). The Indian timekeeping or astronomy texts near Cochin contained detailed accounts of the calculus.

On the epistemic test, those who copy do not fully understand what they copy. This is also evidence of transmission: Clavius got the imported sine values explicitly interpolated to build a larger table but did not know enough trigonometry to calculate the size of the earth. Recall that this size was routinely mentioned in Indian texts and that the size of the earth was a key parameter needed for determining longitudes. (The calendar reform only settled the problem of latitudes.)

There is other circumstantial evidence of transmission of calculus to Europe. Clavius' contemporary, Julius Scaliger, is credited with Julian day-number system which is the same as the Indian *ahargaṇa*. Likewise, another contemporary Tycho Brahe, Royal Astronomer to the Holy Roman Empire, produced the Tychonic astronomical model (in which all planets go round the Sun, which itself goes round the earth) which is just a carbon copy of the astronomical model of Nīlakaṇṭha, stated in his *Tantrasangraha*. Tycho's masonry instruments

(copied from Ulugh Beg's Samarkand observatory) were not accurate enough to make accurate observations of Mars, such as made by Parameswaran over a 50-year period. Nevertheless, Tycho, in those days of the Inquisition, kept some secret documents with which his assistant Kepler decamped, after Tycho's untimely death or murder. Why did Tycho keep mere observations such a secret from his own assistant? How did Kepler, a nearly blind person, arrive at those super-accurate observations, without appropriate instruments (Broad, 1990; Donahue, 1988)?

Likewise, Fermat's challenge problem to European mathematicians, which remained unsolved for long (and was eventually solved by Euler), is taken from an explicitly solved example in Bhaskara's *Bījagaṇita* (87, Colebrooke, 1816, pp. 176–178). Indeed, Bhaskara himself poses it as a challenge, saying "Declare it friend if the method [of solution] be spread over your mind like a creeper." Thus, in Feb 1657, Fermat (*Ouvres*, p. 332 et seq.) asked European mathematicians to solve the problem $Nx^2 + 1 = y^2$ for a given (positive, non-square) N. As examples, he listed, for the case $N = 3$, that $x = 1$, $y = 2$ are solutions and $x = 4$, $y = 7$ are also solutions. Then he asked for the smallest integer solutions for the case $N = 61$ and $N = 109$. This is today called "Pell's equation," and the smallest solutions are the numbers $x = 226153980$, $y = 1766319049$ given by Bhaskara II centuries earlier. Given how large these numbers are, an independent rediscovery would represent a fantastic coincidence.

When the Indian calculus first reached Europe, some people like Fermat and Pascal accepted it enthusiastically, while other people like Leibniz did not fully understand it. (Newton, in his anonymous review of his own report, on behalf of the Royal Society, on Leibniz's charge of plagiarism against him, claimed that Leibniz failed to comprehend the infinite series named after him; Newton, 1714.) Descartes too was unable to comprehend how to sum infinite series. Indeed, Descartes opined that the ratio of curved and straight lines was beyond the capacity of the human mind (Descartes, 1996). In India, children were taught to measure angles as the length of a curved line (the arc) using a flexible string since the days of the śulba sūtra-s (or aphorisms on the string) (Raju, 2009). They could easily straighten the string to compare the length of a curved line with a straight line (and needed to do so to measure the arc in units of the radius).

On the epistemic test, mistakes are proof of transmission. A charitable interpretation of Descartes' blunder is that he was presumably alluding to the infinite series for π, found in Indian texts from long before Leibniz. He thought an infinite series could only be summed by actually carrying out an infinite number of sums and hence regarded an infinite sum as a supertask. Descartes was not the only person who thought thus. Galileo, whose access to the Jesuit archives is well documented, in his letters to Cavalieri (Mancosu, 1996), agreed with this objection and hence eventually left it to his student Cavalieri to take the credit or discredit for calculus.

Newton, himself, claimed credit only for making the calculus rigorous, not for inventing it (though he did claim credit for the sine series). He thought the calculus could be made rigorous by making time metaphysical. Ironically, that was the precise reason why his physics failed (Raju, 1994). Changing that understanding of time/calculus improves physics including the theory of gravitation (Raju, 2012).

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Calendars and Timekeeping Around the World

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The Origins of Calendars and Timekeeping

The measurement of time catalyzed the development of numbers, mathematics and astronomy, and cosmology, as the first humans began counting days, then hours, then minutes, and seconds of time. The methods of timekeeping vary

by civilization and reflect the belief systems, environment, and mathematics of each culture. A more complete treatment of the entire range of calendars and how they arose from each civilization can be found in Penprase (2010).

Many Native North American groups used changes in vegetation and animal behaviors to set their calendars and named their months based on these annual cycles. Like the Hawaiian and Zuni peoples, observations of the moon, sun, and stars would give the "master clock" to reset the calendar and start a new year. The stellar observations could include noting the position of the Big Dipper (also known as the Plough or Ursa Major) relative to the horizon at the beginning and middle of the night, as is the practice of the Mescalero Apache, who know the Big Dipper as *nahakus* (pivot point) (Farrer 1991, p. 48). The Havasupai tribe began their New Year with the heliacal rising of the stars known as the "the Hoop" (Corona Borealis), which marked the New Year in mid-November. The Maricopa and Cocopa tribes of Arizona believed the stars were literally a hand of the creator, and lines of stars were the imprints of his fingers. These stars also worked like the hands of a clock, indicating seasons when plants such as the cactus are ripe which produce fruit in the summer when the Pleiades (*Xitca'*) appear on the eastern dawn horizon (Miller, 1997, p. 199).

The Chumash tribe from Southern California used a combination of weather indicators, plants, and precise observations of the sun to set their calendar. Each year a multiday solstice ceremony took place near the winter solstice using a portable sun stick that included a carved and decorated stone head that was inclined precisely toward the altitude of the winter solstice sun. A series of solar observatories from Southern California were used to measure the solstice, such as the Burrow Flat Cave, Condor Cave, and Window Cave, where beams of sunlight crossed sun figures painted inside the cave to mark the solstice.

Most cultures realize in their count of days the need to provide a reconciliation between the solar and lunar cycles. Reconciling the number of days in the lunar month (29.5333) and the number of days in the solar year (365.2422) was a great challenge for ancient civilizations and has been solved independently with many solar/lunar calendars, such as the Babylonian, Hebrew, and Chinese lunar calendars, as well as the Hawaiian and Hopi solar lunar calendars, which are described below.

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Mesopotamian Calendars

Mathematical advances in Babylonia allowed them to begin to factor and divide large numbers, which in turn allowed them to ascertain whole number multiples of the lunar months and the solar years, such as the 235 lunar month Metonic cycle, which provides a whole number of lunar months (235) and solar years (19), to enable the lunar and solar calendars to match every 6,940 days.

The Babylonians, like many contemporary civilizations, used sets of 12 and 13 lunar month years to reach the 235-month completion of their cycle. These months were named after the various seasons within the Mesopotamian year, and a month began with the visibility of the first crescent moon. A thirteenth intercalary month was added as needed and usually given the name of "second Ululu" or "second Addaru" since it would follow the month of Ululu or Addaru, respectively, to give a complete set of lunar months to a year. Babylonian numbers were written in sexigesimal (base 60) cuneiform, one of the earliest systems of number notation. We still use such sexigesimal numbers in our notation for time (HH:MM:SS), where the colons denote separation between hours, minutes, and seconds.

The Egyptian Calendar

The Egyptian civilization began with a simple calendar based on the 360 + 5 day Egyptian solar year, and three main seasons, named "Inundation," "Cultivation," and "Harvest," divided the year into three parts of 120 days each. Within

the three seasons were 30-day months, each named after Egyptian gods and goddesses. Night and day were each subdivided into 12 equal parts, giving a 24-"hour" day but with hours of different duration depending on the seasons. The word "hour" itself derives from Egyptian timekeeping, since "hour" comes from the Greek word *hora*, which itself derives from the Egyptian word *hor*, which means "day" or "sun's path" (Lennox-Boyd, 2005, p. 22).

The calendar year had 360 days with a 5-day festival period to honor the chief gods of the Egyptian pantheon (Osiris, Isis, Seth, Nephthys, and Horus). Without any correction, the Egyptian calendar year (365 days) would drift with respect to the actual period of the solar year (365.2422 days), to give complete rotations of the seasons over the course of the thousands of years of the Egyptian civilization. A solution to this problem came from the stars. By watching the morning twilight for the first appearance of the star Sirius (the heliacal rising), the Egyptians noticed that Sirius' heliacal rising coincided in time with the flooding of the Nile. By AD 144, an additional month of Thoth was added whenever the heliacal rising of Sirius happened within the last 11 days of the last lunar month (Krupp, 1980). The star Sirius, known in Greek as Sothis, was associated with the goddess Isis, and its heliacal rising coincided with the flood of the Nile, and the Egyptian solar calendar was known as the Sothic year.

Egyptian priests noticed the drift of the Sothic calendar over centuries and were able to improve the match between the days of the year with the motions of the stars by means of the decans system. The decans were a group of 36 sets of stars which could be sighted in the early morning twilight in each interval of 10 days known as a decan. In this way, ancient Egypt had two parallel calendars – one ritual calendar of 365 days subject to some drifting and a more accurate star calendar of the decan stars.

For nearly 2,000 years, the Sothic year was the primary calendar of Egypt and much of the ancient world. However, some attempt to fix the drift of the year was made late in the history of Egypt, in 286 BC, when the Canopus decree of King Ptolemy III added an additional day every fourth year, predating the leap year of the Julian Calendar.

The Ancient Hebrew Calendar

The development of the Hebrew calendar paralleled that of the Babylonian calendar, perhaps due to the Babylonian exile period between 450 and 419 BC. From the first month of Nissannu in the Babylonian calendar (Nisan in Hebrew) to the last of Addaru (Adar in Hebrew), the Hebrew calendar features month names very similar to the Babylonian and, like the Metonic system, inserts extra lunar months over a 19-year cycle. The Jewish calendar is in fact a hybrid of the earlier Canaanite calendar, which started the year closer to the fall equinox, and the Babylonian, which began the year in spring, soon after the Vernal Equinox. This important difference makes the Jewish calendar 6 months out of phase with the Babylonian calendar (Kelley & Milone, 2005, p. 219) (Table 1).

One additional feature shared by the Hebrew and Babylonian calendars is the 7-day week. The book of Genesis includes a description of a 7-day week, with 6 days of labor in which God created the world and a seventh day of rest known as the Sabbath. The word for Sabbath also shares roots in both Babylonian and Hebrew; in Hebrew the word is Shabbat which means "rest," while in Babylonian the word is sabattu or "seventh." For the Babylonians, the sabattu, or seventh day, had ominous associations, as were several other days of the lunar month based on both theology and numerology. For this reason, the seventh day was reserved for rites of purification, and this tradition appears to have been shared by the Greeks and Hebrews (Steele, p. 76).

Like many lunar calendars, the Hebrew calendar relies on sightings of a crescent moon to begin the month. Like the earlier Babylonian calendar, it uses a system of 12 and 13 lunar month years alternating in the 19-year cycle (Rich, 2008), with extra intercalary months added as needed to match the solar year.

Calendars and Timekeeping Around the World, Table 1 Babylonian and Hebrew month names. The Hebrew calendar preserves a snapshot of the Mesopotamian calendar of 430 BC, with very similar month names (but shifted by 6 months), and the same Metonic type lunar calendar as the Babylonian system

	Babylonian		Hebrew		Babylonian		Hebrew
1	Nisannu	7	Nisan	7	Tasritu	1	Tishri
2	Ajjaru	8	Iyyar	8	Arahsamnu	2	Chesvan
3	Simanu	9	Sivan	9	Kislimu	3	Kislev
4	Duzu	10	Tammuz	10	Tebetu	4	Tebeth
5	Abu	11	Ab	11	Sabatu	5	Shebat
6	Ululu	12	Elul	12	Addaru	6	Adar

Additional months in the Hebrew calendar are given the name Adar Sheni or Adar Beit and are added to make for 13-month years, a practice which happens seven times in 19 years. Despite the fact that the main features of the calendar were set in place 2,500 years ago, the first year of the Hebrew calendar is set over 5,700 years ago, in the Gregorian year of 3760 BCE, which is thought by some to be the beginning of the universe as described in Genesis. Each year begins with the first of Tishri, which is the festival of Rosh Hashanah ("head of the year"), to commemorate the creation of the universe and to also observe a time at which the Creator judges the universe. Additional holidays include Yom Kippur, the Day of Atonement, on the tenth day of Tishri, and Hanukah, which always occurs on 25 Kislev in the Hebrew calendar, even though its date will shift each year within the Gregorian calendar. Although the New Year (and universe) is recognized to begin on 1 Tishri, the numbers of the Hebrew months begin with Nisan, as does the Babylonian calendar.

The Islamic Calendar

The Islamic world still sets its sacred holidays with a lunar calendar with 12 lunar synodic months of 29 or 30 days, for a total of 354 days. The beginning of a lunar month is set by the first visibility of the crescent moon, giving rise to the crescent moon as the international symbol of Islam. The beginning of the year is known as Al-Hijra and is the first day of the first month known as Muharram. The Islamic calendar begins its count of years in the year when Mohammed moved from Mecca to Medina and is called the Hijri calendar after this migration, known as the *hijra*. Year 1 of the Islamic calendar corresponds to the day Friday, July 16, 622 CE, making the year 2010 CE in the Gregorian calendar equal to year 1431 AH.

The gap between the Islamic 12 lunar month calendar (354 days) and the solar year (365.25 days) means that the Islamic New Year shifts 11 days earlier each solar year, causing important dates to rotate through the solar year over time. Unlike many other lunar calendars, the Islamic calendar does not allow extra months to reconcile solar and lunar years, since the extra 13th intercalary month is forbidden by the Qur'ān. All of the Islamic holidays will therefore rotate through the solar year. For example, the Islamic New Year dates for 2009 and subsequent years occur on December 18, 2009, December 07, 2010, November 26, 2011, and November 15, 2012, and continue to rotate through the Gregorian solar calendar 11 days earlier each year.

Islamic holidays include the New Year or Al-Hijra and Laylat al-Qadr (The Night of Power), which is believed to be the day when Mohammed first received his revelation that began the Qur'ān. The Qur'ān was revealed to Mohammed during Ramadan, the ninth month of the Islamic calendar, and so the entire month is observed as a month of fasting during daylight hours. The exact date of Laylat al-Qadr varies by country and ranges between the 21st, 23rd, 25th, 27th, and 29th day of the month. During this night, prayers are made and the Qur'ān is studied. The end of the month of fasting occurs on the first day of the following month of Shawwal and is the holiday known as Eid al-Fitr, celebrated by communal

Calendars and Timekeeping Around the World, Table 2 Major Islamic holidays and their significance along with the Gregorian date in 2010 (later years have dates 11 days earlier each year)

Holiday	Date in Islamic calendar	Meaning	Gregorian date in 2010/2011
Al-Hijra	1 Muharram	Date of Mohammed's migration to Mecca (Hijra)	December 07, 2010
Isra al-Miraj	27 Rajab (7th month)	Ascent of the Prophet Mohammed	June 28, 2011
Ramadan	1 Ramadan (9th month)	Month during which Mohammed received revelation of the Quran	August 01, 2011
Laylat al-Qadr	21–29 Ramadan (varies by country)	"Night of Power" – date when Mohammed received first revelation	August 26, 2011
Eid al-Fitr	1 Shawwal (10th month)	"Breaking of Fasting" and end of the month of Ramadan	August 30, 2011
Eid al-Adha	10 Dhu'l-Hijjah (12th month)	Date of Ibrahim's willingness to sacrifice Isma'il; end of Hajj	November 06, 2011

prayers followed by extensive family gatherings and feasting along with an exchange of gifts.

Other important holidays include Isra al-Mi'raj, which celebrates the Ascent of the Prophet Mohammed and occurs on the 27th day of the seventh month of Rajab, and the Eid al-Adha, which is approximately 70 days after the end of Ramadan, on the 10th day of the 12th month of Dhu'l-Hijjah. The Eid al-Adha is a time of prayer and sacrifice of a lamb or other animal, often a goat, and celebrates the willingness of Ibrahim (Abraham) to sacrifice his son Isma'il. This holiday occurs at the end of the hajj (the pilgrimage to Mecca). A summary of the Islamic holidays with their dates and meanings is given below in Table 2.

The Hawaiian Calendar

The ancient Hawaiians developed an original lunar calendar that made use of the lunar months and the position of the Pleiades star cluster to create a stellar-lunar calendar. The year was known as the *makahiki*, and it was divided into two equal sections for summer and winter. The key for maintaining accuracy of the lunar calendar was the synching effect of the Pleiades star cluster, known to the native Hawaiians as *Makali'i* (Johnson & Mahelona, 1975).

The beginning of the first Hawaiian season and the Hawaiian year is in late October or November and is marked by the rising of the Pleiades in the east just after sunset, known as *makali'i-hiki*. The first month begins when the crescent moon is first sighted in the evening (the day known as *hilo*), and sets of 30 nights are counted from this point. Each night had particular associations with agriculture (planting of certain crops were best on particular nights) and religion (including worship of specific gods during the *tabu* or holy nights). The second season of summer began in May when the Pleiades were first sighted in the predawn sky (during their heliacal rising). The twelve 30-day lunar months of the Hawaiian calendar, with their 30 named nights, kept track of the year, but occasionally some months would need to be added to reconcile the annual cycle of the Pleiades with the lunar calendar, much as in other lunar calendars.

By coincidence, Captain Cook's final landing in Hawaii in February 1779 came just after the Hawaiian New Year period, and the Hawaiians may have interpreted Cook's arrival to be an inauspicious premature return of the god Lono, which required a ritual sacrifice to return order to the universe (Ruggles, 2005, p. 179).

The Zuni Calendar

The Zuni observed both solar and lunar calendars. Within the culture is the Sayatasha's Night Chant, in which an actor portraying the masked god Sayatasha keeps track of the days and

months. The actor plants prayer sticks every full moon throughout the year until October for 10 lunar months. After the tenth month, he begins counting the days before the beginning of an intense end of year dance known as *Shalako*, by untying a string which contains 49 knots, 1 for each day. At the end of 48 days, Shayatasa's actor begins the long talk, and he and a set of other masked gods (the *kachinas*) participate in the Shalako dance until dawn. During the final night, the actor recites the precise poem intoned by hundreds of generations of past Sayatasha impersonators, reciting word for word a Night Chant which describes the motions of the sun and moon, the rituals of the people, and their origins.

The Inuit Calendar

The Inuit developed a set of seasonal star markers for measuring the duration of the long winter night, which can last for months. The stars Altair and Tarazed formed the Inuit constellation known as *Aagjuuk*, and these two stars first became visible in late spring and were used to indicate the end of the long winter night. The two top stars of Orion's "shoulders," Betelgeuse and Bellatrix, were known as *Akuttujuuk* and were used to mark the middle of the winter, known to the Inuit as the "dark period." The Pleiades were used to mark time by many different Arctic groups and had the name *Sakiattiak* among the Igloolik, who also used them for navigation. The bright star Arcturus, known to the Inuit as *Sivullik*, or "leader," is visible in the evening sky, being the first star (or leader) to be sighted in the early evening in the west. For the Inuit of Coronation Gulf, Canada, the transit of Arcturus signaled the beginning of the sealing season (MacDonald, Royal Ontario Museum, et al., 1998, p. 78). The Inuit observed a set of 13 lunar months, and a simple system was used to determine whether a year had 12 or 13 lunar months. If the winter solstice coincided with the first day of the thirteenth month, it was skipped, giving a natural alternating pattern of 12 and 13 lunar months over the years.

The Greek Calendar

The early Greek calendar is described in the "works" section of Hesiod's *Works and Days*, one of the earliest surviving works of Greek culture. Celestial observations included noting the heliacal rising of stars and star clusters such as the Pleiades. The Greek year began in October and continued on through September. The Greek days were numbered from 1 to 30, like the Hawaiian month, and included auspicious days for various activities such as "bringing brides home," "giving birth to boys," "planting," "shearing," and "worshipping gods." The days were set by the phase of the moon, with the month beginning at the first sighting of the crescent moon.

Each of the different Greek city-states had different month names, and separate priests would call the beginning of the lunar month and decide when an extra month was needed based on stellar observations. Year names were set relative to the reign of a particular ruler or relative to key events in local history. One technique used to provide a common reference for year names was the Olympic Games, which all of Greece would recognize and which began in the year 776 BC. Any confusion about the Olympic Game number was fixed by attaching to the date the name of the champion of the most prestigious Olympic event, the footrace known as the *stadion*.

The Roman Calendar

The Roman calendar began before the first glimmerings of the Roman Empire, back on the date of January 1, 4713 BC, which sets the origin of the Julian Day count. The Julian Day is still used in astronomy research where the complexities of orbital periods require the use of a uniform count of days. The origins of Roman timekeeping began not in 4713 BC, but in the period of the Roman monarchy, from approximately 776 BC to 509 BC, when the Roman calendar had ten named lunar months. Each lunar month was divided into named days; the "calends" were the first days of the month, the nones were the 5th days of the

month, and the Ides (Idus) were the 13th day of the month.

The "calends" marked the beginning of both the lunar month and a business cycle, in which debts were to be paid at the beginning of the month, before the "nones," with the ides marking the middle of the lunar month. The calendar at first counted only those days when business was being done and featured a 10-month year which started at the vernal equinox. The last of the month names (unchanged to this day) were simply their numerical place in Latin corresponding to "fifth" (Quintilis), "sixth" (Sextilis), "seventh" (September), etc. The months in the Roman Republic were of unequal length – Martius, Maius, Quintilis, and October were all of 31 days, and Aprilis, Iunius, Sextilis, September, November, and December were each of 29 days. After the end of the business and agricultural year, near the winter solstice, the early Romans simply stopped counting the days of the year until the month of the vernal equinox, which would signal the beginning of the New Year.

In order to have a complete annual calendar, the Romans later added two additional months (Januarius, with 29 days, and Februarius, with 28 days) in 509 BC to cover the solar year, adding up to 355 days with 12 lunar months. In order for the solar and lunar years to match evenly, the irregular lengths of the lunar months were supplemented with an intercalary month roughly every other year.

Julius Caesar, as part of his duties as emperor and chief pontiff of Rome, discarded the old lunar calendar in 46 BC. To reform the calendar, Caesar added 10 days to the year by lengthening the five shorter 29-day months by 2 extra days, with the exception of February, which was kept at 28 days with an extra "leap day" added every 4 years. By the time of Caesar's reforms, the calendar had drifted by over 80 days, and so the year 46 BC is known as the "year of confusion" (*annus confusionis*) since it was 445 days long! The result of Caesar's reforms was the Julian calendar, which includes 365 days, with an extra 0.25 days from leap years to give an average solar year of 365.25 days (Steel, 2000). The Julian calendar, with 365.25 days, provides a close match with the length of the solar year of 365.2422 days. Caesar's calendar remained in place for over 1,000 years.

The Julian calendar is still in use today, with the (minor) correction known as the Gregorian reform of 1582 (named after Pope Gregory XIII), which took back 3 of the leap years in centuries not divisible by 4 (1700, 1800, 1900), while retaining leap year in those divisible by 4 (2000, 2400, etc.). The result of the Gregorian reform is to set our modern calendar to have a year of 365.2425 days, which gives an error or "drift" of only 0.0001 days in a year.

The Incan Sidereal Year

For the Inca, time was measured in many ways, from the natural cues of the environment, from the Moon and Milky Way, and from the sightings of stars, planets, and the Pleiades in the night sky.

The motions of the Milky Way in the night sky from 1 month to the next also served as a large "hour hand" of night and provided a similar splitting of the year into four parts. The Inca calendar was also set by heliacal risings of bright stars, star clusters, and dark cloud constellations. The heliacal rising of the brightest star in the Southern Cross (α Cru), associated with *Yutu*, a bird and dark cloud constellation) marked the beginning of the agricultural season, while the rising and superior culmination of the stars α- and β-Centauri (associated with the "eyes of the Llama") coincided with the birth and mating season of the llama. The positions of star clusters were noted both above in the night sky (at zenith or transit) and below under the feet and crops of the Inca (at nadir or inferior culmination). For example, the appearance of the Pleiades or *collca* at nadir, directly beneath the earth, was thought to be a harbinger of the best time for planting (Urton, 1981).

The Inca religion made use of worship sites rotated through the city to various shrines or *huacas* on a daily cycle, arranged along patterns of space that connected the shrines to the horizon and the stars beyond. The ritual calendar linked

all of the 328 *huacas*, one for each of the named days in the 328-day Inca year.

The somewhat unusual number of days in the Inca year comes from the observation of the Incan lunar month, which is based on a unique lunar/stellar calendar. The 27.3 day Incan month was based on the 27.3-day sidereal period for the moon to return to the same position against the stars, as opposed to the more familiar 29.5-day lunar synodic month of most other cultures. The Inca would carefully watch the location of the moon in the sky relative to the stars to determine the beginning and ending of lunar months. Groups of 12 lunar sidereal months combined to create an Incan year of 328 days, giving the annual calendar, but also leaving behind a group of 37 days which were uncounted (Aveni, 1997).

Calendars of Ancient India

Another culture that made use of the moon's position relative to the stars was ancient India, where the practice of Hindu astrology required the use of moon and star coincidences known as *nakṣatras*. Like the Inca, the early Hindu astrologers would watch the position of the moon against the background of a set of indicator stars, which set the lunar sidereal calendar. For determining auspicious dates of weddings and births, the Hindu astrologer would combine the lunar phase of the date with the lunar sidereal location or nakṣatra to get a more precise reading of the sky.

The nakṣatra system dates to before 1000 BC, in the era of the *Ṛgveda*, a collection of Vedic Sanskrit hymns. A set of 27 stars were chosen near the ecliptic plane as references for gauging the position of the moon as it moves through its 27.3-day lunar sidereal cycle. The stars, their corresponding names in Hindu and European astronomy, and the corresponding constellations are presented below in Table 3.

The Hindu astronomers divided the ecliptic into 27 nakṣatras and also divided the sky during any individual day into 27 parts, known as *yogas*. The yogas (analogous to hours) were based on the angular distance along the ecliptic of the sun and moon, which set a reference point on the sky, and from this point divided the sky into 27 regions 13.333° wide. Additional terms and concepts of interest to the Indian astronomers and astrologers include the *tithi*, which is defined as the angular distance between the Sun and moon (something akin to lunar phase), and the *karaṇa*, the time required for the distance between the sun and moon to increase by a distance of half of a *tithi*.

The Hindu solar calendar functioned much like many other calendars, with a New Year beginning with the first lunation after the Vernal Equinox, in April. A set of 12 solar months, or *rashi*, was observed based on the sun's position within the ecliptic. Each of the 12 named solar months included 1 of the 12 named lunar months. The named lunar months include (in order): Chaitra, Vaishākh, Jyaishtha, Āshādha, Shrāvana, Bhādrapad, Āshwin, Kārtik, Mārgashīrsha Paush, Māgh, and Phālgun. Each lunar month is matched with a solar month, and lunar events determine any corresponding festivals within that month. For example, when the sun is Capricorn, during January, it is the tenth solar month (*rashi)*, known as Makar, and the lunar month is known as Paush. A festival (or *mela* in Bengali) in this month in the province would be known as *paush mela*. A summary of the month names within the Indian calendar is shown in below in Table 4.

The Hindu calendar, like many ancient calendars, included a 7-day week. Days of the 7-day week in the Hindu calendar, known as the *vaasara* in Sanskrit, are named after the 7 celestial bodies known to the ancients, in the same order as in the Western calendar. The sequence of days (in order) includes days named after the Sun, Moon, Mars, Mercury, Jupiter, Venus, and Saturn, which in Sanskrit are Ravi, Soma, Mangala, Budha, Guru, Shukra, and Shani, respectively. Therefore the Indian day names are Ravi vasara (Sunday), Soma vasara (Monday), Mangala vasara (Tuesday), Budha vasara (Wednesday), Guru vasara (Thursday), Shukra vasara (Friday), and Shani vasara (Saturday).

Since India as a modern country is very diverse, with 22 officially recognized languages,

Calendars and Timekeeping Around the World, Table 3 Hindu nakṣatras, used to mark the path of the moon through the stars during the 27.3-day lunar sidereal month (Ojha, 1996)

Nakshatra	Location on sky	Shape	Stars
1. Ashwini	and γ Arietis (head of Aries)	Face of horse	3
2. Bharani	35, 39, and 41 Arietis	Yoni	3
3. Krittika	Pleiades + Alcyone	Curved knife	6
4. Rohini	Aldebaran	Cart	5
5. Mrigashira	λ and ρ Orionis	Face of deer	3
6. Ardra	Betelgeuse	Jewel	1
7. Punarvasu	Castor and pollux	House	4
8. Pushya	γ,δ, and τ Cancrii	Arrow	3
9. Ashlesha	δ,ε,η, and σ – Hydrae	Circular	5
10. Magha	Regulus	House	5
11. Poorva-phalguni	δ and τ Leonis	Manchaka	2
12. Uttara-phalguni	Denebola	Small cot	2
13. Hasta	Spica	Hand	5
14. Chitra	α to ε Corvi	Pearl	1
15. Swati	Arcturus	Coral	1
16. Vishakha	α,β,γ, and ι Librae	Torana	4
17. Anuradha	β,δ, and π Scorpii	Vali	4
18. Jyeshtha	α,σ, and π Antares	Circular earring	4
19. Moola	$\varepsilon,\zeta,\eta,\tau,\iota,\kappa,\lambda$ Sco (tail and stinger of Scorpius)	Tail of a lion	3
20. Poorva-shadha	δ and ε Sagittari	Tusk of an elephant	11
21. Uttarashadha	ζ and σ Sagittari	Manchaka	2
22. Shravana	α,β, and γ, Aquilae (Altair)	Aeroplane (??)	3
23. Dhanishta	Delphinus	Mridanga	4
24. Shatabhisha	γ Aquarii	Elliptic	100
25. Poorva-bhadra	α and β Pegasi (Markeb)	Manchaka	2
26. Uttara-bhadra	γ Pegasi and α Andromedae	Twins	2
27. Revati	ζ Piscium	Mardala	32

and over a dozen separate historic cultures within its borders, there is a good deal of variation in the names of months, days, and timing of festivals that reflects the linguistic and religious diversity of the country. The effects of precession are causing many of the ritual holidays of India to lose their astronomical underpinnings, such as coincidence with solstice or equinox dates (Aslaksen and Rugulagedda 2001; Nath, 2008).

In the Hindu cosmology, time unfolded in a set of four ages, in a descent from pure order into decay, before destruction and renewal. The first of these ages was known as *kritya* or *satya* and was symbolized by the bull of creation on all four legs. This first age lasted 4800 "divine years," which corresponded to 1,728,000 of our "human years." During this first age, the universe was in a state of purity, and the laws of dharma, rules that are in accord with order, were obeyed. The second age was known as *treta*, and in this age of 3,600 divine years (1,296,000 human years), the first hints of decay are visible, and the cosmic bull is symbolized to have only three legs. The third age was known as Dvapara and lasted 2,400 divine years (864,000 human years), and the fourth and final age was the age of Kali, which lasted for 1,200 divine years (432,000 human years). After these four ages were complete, there would be a short period of twilight known as sandhya, or sandhyamasha, before the age would be complete, and a cycle of destruction and recreation would bring the universe back into its pure *kritya* state (Dallapiccola, 2003).

The enormous grouping of this vast expanse of time in the four ages comprised the length of time known as the *mahāyuga*, or "great cycle." Each

Calendars and Timekeeping Around the World, Table 4 The Hindu and traditional Indian calendar included both solar months and lunar months (source: http://www.nationmaster.com/encyclopedia/Hindu-calendar#tithi)

Solar months	Season	Gregorian months	Zodiac
Mesh	Vasant	April/May	Aries
Vrushabh	(Spring)	May/June	Taurus
Mithun	Grishma	June/July	Gemini
Kark	(Summer)	July/August	Cancer
Simha	Varsha	August/September	Leo
Kanya	(Monsoon)	September/October	Virgo
Tula	Sharad	October/November	Libra
Vrishchik	(Autumn)	November/December	Scorpius
Dhanu	Hemant	December/January	Sagittarius
Makar	(Autumn-winter)	January/February	Capricornus
Kumbha	Shishir	February/March	Aquarius
Meen	(Winter-spring)	March/April	Pisces

grouping of four ages amounted to approximately 4,320,000 years and comprised a brief segment of a dream within the sleep of Brahma. One thousand of these cycles created a length of time known as the *kalpa*, which amounts to about 4.3 billion years, close to the current scientific estimate of the age of the earth, the sun and the solar system. This enormous expanse of time was also imagined to be the length of one full day in the life of Brahma.

Chinese Calendars

The Chinese recognized a set of five elements that describe all earthly and celestial phenomena. The five named elements included wood, fire, earth, metal, and water, which had celestial counterparts in the planets Jupiter, Mars, Saturn, Venus, and Mercury, respectively. The solar year was also divided into five seasons, one for each element. The cycles of time and motions of the heavenly objects tied into these numbered elements and connected the essence of these elements to life on earth. Motions of the planets and appearances of "guest stars" and "sweepers" (now known as supernovae and comets) gave a picture of the universe that reflected the heavenly mandate of the emperor on earth.

The Chinese also divided space into systems that included 4, 10, 12, and 28 parts, which arose from both ancient folk traditions and Chinese philosophy developed over thousands of years. The ancient Chinese believed that each of the four cardinal directions had a symbolic animal and color, much like many Native American peoples.

The Chinese animals and colors include the Black Warrior/Tortoise for North, the Red Bird for South, the Blue Dragon for East, and the White Tiger for West. Early Shang writings refer to "Ten Heavenly Stems" and "Twelve Earthly Branches," a set of reference stars set the calendar, and the planet Jupiter, respectively. The Heavenly Stems provided a system similar to the decan stars of the Egyptians and helped synchronize the calendar with the seasons. The Earthly Branches were a timekeeping system in which the 24-h day (and the sky) was divided into twelve segments, named after animals from an earlier folk tradition. The motions of the planet Jupiter would circle the sky in a 12-year cycle, the basis of the Chinese Zodiac which assigns 1 of the 12 Earthly Branches (rat, bull, tiger, hare, dragon, serpent, horse, sheep, monkey, rooster, dog, and pig) to each year as Jupiter moves through its 12-year synodic period. The 28 *xiu* or lunar mansions also helped set the Chinese calendar, as they could be observed at dawn or sunset to help set the calendar.

Professional Chinese astronomical records cover over 1,600 years of observations, from approximately 200 BC to 1400 AD and provide rich material for dating ancient astronomical

events. Below are samples of Chinese observations of ancient supernovae, translated from the original records:

> "A star appeared to the south of the Ti lunar mansion, east of Ku-Lou and west of Chi-Kuan. At one time it resembled the half moon, shown with pointed rays, and was so bright that objects could be seen by its light" (description of the Supernova of 1006)
>
> "..it was visible by day, like Venus; pointed rays show out from it on all sides; the color was reddish-white. Altogether it was visible in the daytime for 23 days" (description of the Crab Supernova of 1054)
>
> "The star was as big as a peach. . .." (description of Supernova of 902 AD, which was also visible for a year).
>
> (Kiang, 1969; Shen, 1969)

Maya Timekeeping and Calendars

The interlocking calendars of the Maya contained two short-term calendars, the *tzolkin* and the *haab*, which were based on a 260-day cycle of 13 × 20 day months, and a 360 + 5-day cycle of 12×30 day months. In addition to these two calendars, the Maya kept track of cycles of much larger eras or eons of time, by bundling the days into groups of 20 and 13, into what we would call centuries, millennia, and 10,000-year periods, which the Maya called tuns, katuns, and baktuns.

The Mayan number system was developed to keep track of extremely large numbers from timekeeping and is unique in two aspects: (1) the use of a base-20 number system (common to Mesoamerican people, but perhaps invented by the Maya) and (2) the development, independent of Indian and Arabian mathematicians, of the number zero.

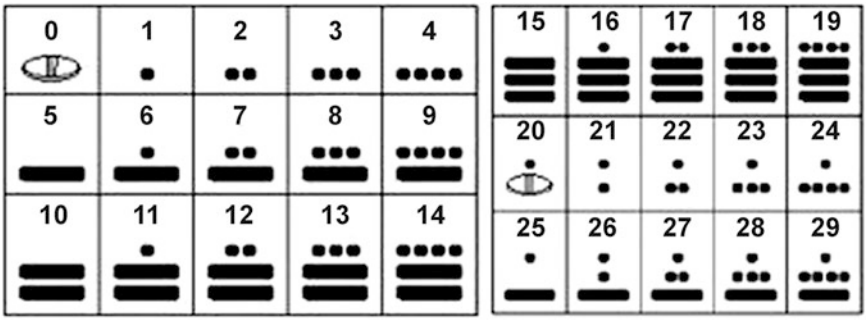
Examples of Mayan numerals are given below and are part of a base-20 number system, as opposed to our base-10 number system (Fig. 1).

By grouping days into bundles of 20 named days, the Maya formed the basis of the "week" in their calendar, which when combined with 13 sacred numbers made a 260-day cycle known as the *tzolkin*. The word tzolkin or tzolk'in means "count of days" in Yukatek Maya and was the fundamental basis for the Mayan calendar. Each of 20 named days rounding through a cycle with 13 numbers made a cycle known as the *uinal*, or a Mayan week, in which 20 days were grouped. Each day name would be paired with a number, until the *uinal* was complete. The pairings would continue until every possible pairing of 20-day names and 13 numbers had been made, after 260 days.

The combination of 20-day names and 13 numbers provided the fundamental cycle of time for the Maya. Some have likened the process of pairing names and numbers to interlocking wheels; one wheel would have 13 numbers and would rotate next to a wheel with 20 names. The imaginary assemblage would continue rotating until all 260 pairs had been made.

A period of 260 days does not easily match with lunar months, the solar year, or even the motions of Jupiter. However, many authors have noted that 260 days is roughly half the period of the Venus year – the time Venus spends within either the Eastern or Western sky before disappearing in the glare of the sun. The period between maximum elongations of Venus is 584 days, which divides into two 260-day periods for visibility and two 32-day periods in which Venus crosses either behind or in front of the sun.

Since the Maya needed to maintain crops and time their activities with the stars, a second calendar was needed to fix dates within the solar year. The official count of solar days for the Maya was known as the *haab*, or "vague year," and took secondary importance to the tzolkin. The haab operated much like the tzolkin but had its basis in 18 named months, with 20 numbered days, and operated somewhat more simply, with its names consisting of 1 of 18 month names, and 20 numbers, progressing along with day names such as "1 Pop," "2 Pop," "3 Pop," etc., until 20 was reached, and then the next month would be used. The 18 named months and 20 numbered days together gave a 360-day period, close to the solar year, known as the *tun*. To keep the calendar from drifting, an extra unnamed (and very unlucky) 5 days were added to the end. The year-ending days were known as the *uayeb* to give a 365-day solar year, much as in the early Egyptian calendar, except the uayeb was a time of



Calendars and Timekeeping Around the World, Fig. 1 Examples of Mayan base 20 (or vigesimal) numerals, showing their representation of zero (developed independently from Indian and Arabian mathematicians) and counting with groups of *dots* and *bars* representing ones and fives, respectively, until reaching 20, the base number for their number system (Source: http://commons.wikimedia.org/wiki/Image:Maya.jpg)

dread instead of a time of festivities. Groups of 20 of the haab years formed the grouping known as the *baktun*, which is analogous to a Mayan decade.

The Calendar Round

The combination of a tzolkin date and a haab date gives a unique number name combination that uniquely specified a day within the Mayan calendar cycle. Some basic mathematics will show that the two cycles will both repeat after $73 \times 260 = 18{,}980$ or $4 \times 13 \times 365 = 18{,}980$ days, which corresponds to about 52 solar years. The pairing of these two cycles forms the basis of the shortest and most profound of the Mayan cycles of creation and destruction, the Calendar Round. The intermeshing of these two calendars can also be visualized as a set of two imaginary wheels, and when both wheels have turned through all combinations of tzolkin and haab names (after 18.980 days or 52 years), the calendar round would be complete.

The year bearers for the Maya were the days *Kan*, *Muluc*, *Ix*, and **Caucac**, associated with the Chac Gods in the four cardinal directions of East, North, West, and South. The four different types of years required four different New Year ceremonies, soon after the Winter Solstice. During a New Year ceremony, offerings of corn and sacrificial animals would be made, and a procession would bring a large number of people into town through the appropriate cardinal direction (Sharer & Traxler, 2006, p. 550). Most dreaded were the *Caucac* years, which were associated with dreadful calamities such as swarms of killer ants or flocks of crop-destroying birds. For these years more elaborate ceremonies were performed.

After the completion of the 52-year cycle, the Aztec New Fire Ceremony included observations of the Pleiades to see if it stopped its motion in the middle of the night, signifying the end of the present world. Upon observing that the Pleiades were not frozen on the sky, fires were lit, and chants were sung to help renew the world and preserve order in the cycles of the heavens. The presence of fires atop the mountains could be seen far away, signaling the renewal of a new cycle to the villages below.

Larger groupings of time, analogous to our centuries and millennia, were also of great interest to the Maya. The first of these is the *katun*, mentioned earlier, which is a group of 20 tuns, which amounts to 7,200 kins, or about 20 years or 7,200 days. Of particular interest to the Maya was the ending of each *katun* or 7,200-day period. Mayan monuments provide excellent records of the Mayan kings during the Classic and Late Classic periods and include long count dates (Sharer & Traxler, 2006, p. 546).

Groupings of 20 *katuns* form a *baktun*, which is 144,000 days, or about 394 years. These very

long groupings of days form the basis of a Mayan long count date, which would record in each digit the number of baktuns, katuns, uinals, and days since the beginning of the current age within the long count. By adding together all of the numbers and the corresponding bundles of days, it is possible to place a date exactly relative to the beginning of the current age. A long count date would be completed by including the *tzolkin* and *haab* designation for the date at the end.

As an example, to specify a long count date, one might see the following numbers and names:

9.15.10.0.10 3 Ahau 3 Mol

The long count date specifies in its five (base 20) digits the number of days since the beginning of the current age. The example above would include (starting from the left, which counts the largest grouping of days):

9 × 20 × 18 × 20 × 20 + 15 × 20 × 18 × 20 + 10 × 20 × 18 + 0 × 20 + 10 days = 1,407,610 days

For this example, as we add up the days we include 9 *baktuns* (1,296,000 days) +15 *katuns* (108,000 days) + 10 *tuns* (3,600 days) + 10 kin (10 days) which places the Mayan long count date 9.15.10.0.10 1,407,610 days from the beginning of the universe.

The date also corresponds to a unique date in the two tzolkin calendars and can be tied to our Gregorian calendar. For our example, the long count date above, 9.15.10.0.10, is named *3 Ahau 3 Mol* in the Mayan calendar, or June 30, AD 741, in the Gregorian calendar (Sharer, p. 574).

The beginning of the universe, which forms the origin of the Mayan time-based cosmology, corresponds to the Gregorian date of 13 August 3114 BC. On the first day of the age, we would have the long count date of:

0.0.0.0.0. with Mayan day names 4 Ahau 8 Cumku = 13 August 3114 BC

The very ancient date of 3114 BC predates the Mayan civilization, since the oldest known long count date from Mayan archaeology is from Stela 2 at Chiapa de Corzo, which is listed as approximately 114 BC. Presumably, the beginning of the calendar in August of 3114 BC is simply a result of numerology and mathematics, much like the beginning of many other calendars we have seen. Other calendars with such beginning dates include the Julian dates, which begin in 4713 BC, the Jewish calendar, which begins in 3761 BC, the ancient Greek Olympiad-based calendar, which placed the first Olympics in 776 BC, and the Greek Orthodox calendar, which begins in 5509 BC (Sharer & Traxler, 2006, p. 568).

The last date of the current age is when the leftmost zero (the *baktun* indicator) goes from 12 to 13, which corresponds to the last day of the current age

12.19.17.19.19 -> 13.0.0.0.0 = 23 December, 2012 AD

The time between these dates, which would be the duration of the age we live in, is 13 *baktuns*, 1,872,000 days or 5,200 years! The Mayan astrologers would expect that at this date we would have a complete renewal (and destruction) of our world, but also with the expectation that life and time would begin again, in an endless cycle of recurrent events.

The Long Count and Cycles of the Universe

The largest cycles of days for the Maya come into play in the form of the long count described above, which describes ages of 5,200 years. However in some contexts (such as in monumental carved stoned stelae), long count dates would be specified in an even longer format, with two additional digits beyond the usual five places of the long count. Below is an example.

13.13.13.3.11.8.0.19 5 Imix 9 Kanka

These additional digits refer to even longer units of time, which would be groups of 20 × 400 years (a *pictun*), 20 × 20 × 400 years

(a *calabtun*), 20 × 20 × 20 × 400 years (a *kinchiltun*), and 20 × 20 × 20 × 20 × 400 years (an *alautun*), corresponding to cycles of 8,000; 160,000; 3,200,000; and 64,000,000 of the Mayan *tuns*. The number of solar years within each of these units of time is slightly less than the number of *tuns*, since a *tun* is 360 days, and the solar year is 365.2422 days. The largest of these time units recognized by the Maya is the *alautun*, which corresponds to about 63,000,000 solar years, or 23 billion days!

To summarize the complete set of Mayan time units we provide the following listing of the many units within their reckoning of time below. Each line in the summary below corresponds to one position in a long count date.

Summary of Mayan units of time
1 kin or 1 day
20 kins = 1 uinal or 20 days
18 uinals = 1 tun or 360 days or ~ 1 solar year
20 tuns = 1 katun or 7,200 days ~ 19.7 solar years
20 katuns = 1 baktun or 144,000 days = 400 tuns ~ 394.24 solar years
20 baktuns = 1 pictun or 2,880,000 days = 8,000 tuns ~ 7885.25 solar years
20 pictuns = 1 calabtun or 57,600,000 days = 160,000 tuns ~ 157,703 solar years
20 calabtuns = 1 kinchiltun or 1,152,000,000 days = 3,200,000 tuns ~ 3,154,000 solar years
20 kinchiltuns = 1 alautun or 23,040,000,000 days = 64,000,000 tuns ~ 63,000,000 solar years

(Sharer & Traxler, 2006)

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Calendars in East Asia

Nakayama Shigeru

Successive attempts to improve a typical luni-solar calendrical system for reconciling two fundamentally incommensurable periods – the tropical year and the synodic month – were made throughout

the history of Chinese and Japanese calendars until their replacement by the Gregorian solar calendar in modern times, the Japanese in 1883 and the Chinese in 1912.

The length of a synodic month varies between 29.0 and 30.1 days. The luni-solar calendar provided for "short" months of 29 days and "long" months of 30 days. Calendrical scientists attempted to arrange short and long months so that the moon's conjunction would take place on the first day of every month. The day notation of the lunar month represented the phase of the moon; for instance, the 15th day of the month was always a full moon, while the 1st day was a new moon.

In addition, the Chinese had an independent system of solar intervals (*qi*) for indicating seasonal changes, the most important phenomena in the regulation of agriculture. The tropical year was divided into 12 equal intervals of time, the element of a purely solar calendar. The middle point of each interval was called its *zhongqi* or interval center. The synodic month was always slightly shorter than an equal interval, and thus an interval center did not occur in certain months. Such months were designated as intercalary months, and in this way the sequence of synodic months was reconciled with the seasons of the tropical year. The year that included an intercalary month had 30 synodic months. This occurred roughly once every 3 years.

The Chinese calendar calculators were, however, not satisfied with providing a conventional calendar, in which the courses of the sun and moon were reconciled, merely for civil use; they also tried to include the anomalistic motions of the sun and moon.

Prior to the Tang period (roughly seventh to ninth centuries), a mean synodic month of approximately 29.5306 days was used for this purpose. Shortly before the Tang, however, a proposal was made to take anomalistic motions of the sun and moon into consideration in calendar making. Liu Zhuo (AD 544–610) used the term *dingshuo* (true synodic month) as opposed to the older concept of *pingshuo* (mean synodic month). During the Tang period the idea of the true synodic month was adopted in the official calendar in order to attain better agreement with the actual phases of the moon, and also for convenience in eclipse-prediction calculations.

Liu Zhuo also made the first recorded distinction between *dingqi* and *pingqi*. The former is the period of time for the sun to move through a 30° angle of the ecliptic (the band of the zodiac through which the sun apparently moves in its yearly course), which therefore varies in length in accordance with the anomalistic movement of the sun. The latter is the average length of time to move through a 30° angle. This concept, *dingqi*, however, was not actually adopted in the official calendar until the Qing period (the seventeenth century on).

Daily life is never affected by such small discrepancies in the calendar as those due to the anomalistic motions of the sun and moon. The astronomical attainments of the Chinese calendrical schemes went far beyond the concern of the common people. They included not only luni-solar phenomena but also the periodic motions of the five planets. They were called *li*, which corresponds to "ephemeris" as well as "calendar" in the narrow sense.

In the case of the Julian calendar reform data were doubtless gathered from prior calendars and not from actual observations. One recalls in this connection Lillius' effort in the Gregorian calendar reform to reduce the toil of observation and computation so as to provide an artificial system independent of astronomical tables and indeed of any link with actual celestial phenomena. The Western calendar was not, in terms of astronomical precision, overwhelmingly rigorous.

The difference of purpose between calendar-making in the West and East is clear. Whereas the Western calendar was divorced from the development of astronomical science, and aimed at schematic convenience for civil and religious proposes, the East Asian calendar, disregarding civil convenience, was an attempt to represent

faithfully the movements of the heavenly bodies. It thus became much more complicated than its practical applications warranted. A sharp separation of scientific astronomy and civil calendar-making did not take place in traditional East Asia. Its scope was confined to the composition of a luni-solar ephemeris which stood or fell on the accuracy with which it could predict eclipses, which is the best way to check the validity of any luni-solar calendar. Analysis of planetary motions was rather ancillary to the main stream of Chinese calendar making.

Cosmological discussions often took place during the Han and Six Dynasties periods (second century BCE to sixth century AD), although they were discontinued soon after. In the Tang period the Chinese astronomers were no longer interested in this particular speculative pursuit. While occasional cosmological debates were found among philosophers, scientific cosmology was long set aside and forgotten in professional calendrical science circles until the time of the Jesuits' impact in the seventeenth century.

Perhaps the most striking thing about the recastings of the civil calendar in China was their frequency. In 2,000 years there were more than 50 revisions of the Chinese calendar, and then of the Japanese calendar, whereas in the West there was only one major reform, the Gregorian. Why were the Chinese so preoccupied with the calendar that they were driven to such repeated efforts? There were two major reasons, one political and the other technical.

Among the ancient Chinese the idea prevailed that a ruler received his mandate from heaven. In the early period, therefore, after important changes within individual reigns and always after important changes of dynasty, the new emperor was prompted to reform key institutions, especially the official calendar, in order to confirm the establishment of a "new order" which a new mandate implied. A new mandate meant a new disposition of celestial influences. The Han Emperor Wu (r. 1480–1487 BCE) was advised by his councilor to revise the calendar and change the color of ceremonial vestments, in order to make it clear that his rule was based on a true mandate. The result was the imperial edict by which the *Taichu* calendar was adopted.

This notion was responsible for the subsequent course of development of Chinese calendrical science. Calendrical science enjoyed governmental sponsorship throughout its history, and had more prestige than other branches of science; it was China's most genuine contribution to the exact sciences. The history of Chinese and traditional East Asian astronomy is, for the most part, the history of calendar-calculations.

In the course of time, however, the political importance of calendar reform dwindled. The restriction of calendar reform to change of dynasty was not strictly observed by the Northern Wei (fifth century AD) and succeeding northern dynasties. Some rulers unduly took advantage of calendar reform to gain or regain popular support. The calendrical significance and authority of calendar revision were thus largely lost. In the Tang dynasty, the motive for calendar reform became simply to correct disagreements of the calendar with observed celestial phenomena. Hence, reforms were carried out whenever a small error was found. This accounts for the frequent revisions in later phases.

Beyond the concern with timekeeping, the Chinese astronomers dealt mainly with apparent solar and lunar movements and eclipse prediction. The Chinese luni-solar calendar required revision whenever the discrepancy between calculation and observation became noticeable. For this purpose, the government founded the Office of Astronomy, and incumbent astronomers were responsible for the improvement of the calendar. The government enjoyed a monopoly on the regulation of time, which contributed to imperial control of daily life and which strengthened the central power and prestige at a sacrifice of civil convenience. People were forced, in matters of everyday life, to follow a calendar based on a complicated, "astronomically rigorous" and "state-authorized" ephemeris, which, unlike our

solar calendar, could never be prepared by laymen, but depended on the skill of official astronomers.

Despite early recognition that a single perpetually valid calendrical scheme was impossible, the calendar calculators never tired of proposing revisions. Their incentive must be ultimately attributed to the rational desire to conform to the celestial order, a philosophical compulsion to accept the phenomena of the material sky as the most authentic reality. It was because of this orientation that calendar-making maintained its status as an integral part of Chinese science and learning for such a long time.

Modernization and Westernization

As the official calendar was quite an important part of the social system, westernization in modern times was first infiltrated through calendrical science.

Western astronomy had arrived in China with the Jesuits in the sixteenth century. Calendar-making was a vital function of the Chinese bureaucracy, and the Jesuits hoped that by demonstrating the superiority of Western astronomy they would succeed in persuading the bureaucratic elite that Western cultures and Christianity were superior. Astronomy was well suited to their purposes, not only because it was so important to the Chinese bureaucracy but because the phenomena with which it dealt possessed a universality that transcended ► East and West, and the objectivity of celestial phenomena did not permit much human manipulation. Furthermore, it was quantitatively precise. Thus, when the tally sheet was in, Chinese astronomers had to acknowledge that Western astronomy had superior features. All that the Jesuits made available from Western tradition, however, were peripheral data and methods of calculation. The structure, styles, and purposes of Chinese calendrical astronomy remained unchanged. As Xu Guangqi, a high Chinese official who collaborated with the Jesuit Matteo Ricci on several projects, put it, "We melted down their materials and poured them into the *Datong* (the traditional Chinese calendar then in use) mold."

In Japan, the eighth Shogun Yoshimune (1644–1751) attempted to use this refurbished Chinese astronomy as the basis for calendrical reform, but he was effectively opposed by conservative court circles in Kyoto. The revision of Horeki that came into effect in 1754 was still modeled upon the traditional *Shoushi* calendar. Yoshimune's desire was fully realized, however, in the Kansei revision of 1797.

After that, the scientific quality of the traditional luni-solar calendar was improved and perfected, but still the traditional mold was maintained throughout the Tokugawa period (1603–1867).

Despite the earlier recognition of Western superiority in science, a radical change of political institutions in Japan had to precede the official adoption of the Western Gregorian calendar in 1873. The decisive factor in the adoption of the Gregorian calendar was the high value the government placed on westernization. Many Japanese proposed a more reasonable solar calendar at the time of the reform, but the government preferred the Gregorian, despite its obvious shortcomings, because of diplomatic relations with the West.

With the establishment of the Republic of China in 1912, the Chinese luni-solar calendar was officially abolished.

To what extent the Gregorian calendar was observed among the populace is questionable, but after the second World War, it became firmly established in everyday life in East Asia.

See Also

► Astronomy
► Time

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Calendars in Egypt

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Otto Neugebauer (1969, 81) described the ancient Egyptian civil calendar as "the only intelligent calendar which ever existed in human history." His statement can be appreciated by tracing the ancient Egyptians' gradually developing sense of time from an initial awareness of the day to the full realization that the year had a constant length of 365 days. The introduction of the Egyptian civil calendar, based on solar years as opposed to lunar years, resulted in the development of our present-day Gregorian calendar.

Humans first became conscious of the existence of the day through the regular reappearance of the sun after its disappearance the evening before. Observing the regular change of one crescent moon to the next, they became aware of the longer time unit of the month. The practical demands of temple administration led them to develop their ability to count and calculate and they realized that one lunar month was made up of 29 or 30 days.

With the advent of agriculture in the Nile Valley, the season, rather than the month, gained importance as a subunit of the year. This agricultural calendar was based on a regularly recurring event, the Nile flood, whose return it was desirable to predict with a fair degree of accuracy. The ancient Egyptians must have realized that a purely lunar calendar was not capable of adequately predicting such annual events. They hit upon another device by which the onset of the inundation could be determined – the heliacal rising of Sothis (Sirius, the brightest star in the sky). They observed that after a 70-day period of invisibility, Sothis could be seen again just before sunrise, and this heliacal appearance of the star was taken to signal the beginning of the new year.

The Egyptians, having reckoned that there was a 365-day span between two successive heliacal risings of Sothis, initially resorted to a luni-stellar calendar which consisted of 12 lunar months totaling 354 days, to which an additional intercalary month was added every few years to make up for the cumulative discrepancy arising from the 11-day difference between the lunar and stellar year. The rule used was that whenever Sothis rose during the last 11 days of the fourth month of the last season, an intercalary month should be added.

Although the luni-stellar calendar could set the time for observance of religious festivals, which were typically agricultural in origin, a more practical calendar was required to meet the demands of the state administrative system. Thus, the Egyptians adopted a 365-day civil calendar which was divided into three seasons, each of four 30-day months. The year consisted of 12 months, each of 30 days, plus "five days upon the year." Events were officially dated as occurring on the first, second, third . . . day of the first, second, third . . . month of the specific season of a particular year in the reign of the current pharaoh. In New Kingdom documents, the 12 months are often given individual names which originated from the cultic celebrations connected with these months: (1) Thoth, (2) Phasphi, (3) Altyr, (4) Choriak, (5) Tybi, (6) Mechir, (7) Phamenoth, (8) Pharmuthi, (9) Pachon, (10) Payni, (11) Epiphi, and (12) Mesori. These names of months are still preserved in Egyptian folk astronomy and meteorology.

Each of the 30-day months of the civil calendar was divided into three 10-day "weeks" or decans. Thus, there were 36 decans each year [Symons 2007]. The Egyptians defined each decan to begin when a particular star or

constellation appeared on the horizon just before sunrise. In the New Kingdom, the decan hours came to be measured in terms of the local meridian, rather than the horizon (Belmonte 2003). The period of time between the appearance of one decan on the horizon and the next was defined to be an hour. From the surviving "diagonal calendar" examples, it is clear that the night was considered to contain only 12 h rather than the 18 which might have been expected when we consider that we see approximately half the celestial sphere on any given night. The discrepancy seems to arise because the Egyptians did not include the period of twilight or dawn as part of the night. Only the period of totally darkened sky corresponded to the term "night."

The idea that the day also included 12 h seems to be developed merely in analogy with the night. These hours might be measured on a shadow clock, since the length of shadow cast by any object changes relative to the position of the sun in the heavens. The shadow does not just change over the course of the day, however, but also over the course of the year as the sun travels between the tropics. As a result, these shadow clocks give no more than an approximation of true equal hours. The use of clepsydra (water clocks), in which water escapes from a graduated container at a regular rate, would provide a measurement closer to our modern concept of equal hours.

The Egyptian calendar constructors and timekeepers did not go beyond the hour in measuring time. It is to the Babylonians, with their sexagesimal mathematical system, that we owe our modern concepts of 60 min in an hour and 60 s in a minute.

In time, the Egyptian 365-day calendar became completely out of step with the actual tropical year, since it fell behind the latter by 1 day every 4 years. Thus, in 4×365 years, i.e., in 1,460 years, the civil year would have lost a complete solar year and would again correspond with the seasons. This 1,460-year period is generally referred to as the "Sothic cycle" and reflects the fact that every 1,460 years the so-called heliacal rising of Sothis fell on New Year's Day and thus marked the onset of a new Sothic period. The Egyptians seem not to have been concerned by the discrepancy between their civil calendar and the true solar year.

Early attempts to calculate the date of the introduction of the civil calendar based on the period of the Sothic cycle and on the assumption that the civil calendar would have coincided with the luni-stellar cultic calendar when it was first introduced have been discredited by more modern scholarship. At present, there is no satisfactory answer to the question.

In 238 BCE, Ptolemy III proposed to bring the civil calendar into synchronization with the solar year by adding an extra epagomenal day every 4 years. His attempt did not find widespread acceptance. Modification of the ancient calendar only ensued two centuries later when, after Julius Caesar's conquest of Egypt in 46 BCE, he followed the advice of the famous Alexandrian astronomer, Sosigenes, and adopted a modification of the ancient civil calendar for the Roman Republic. Sosigenes suggested that the length of the year should be 365 and a quarter days, that there should be a 4-year cycle containing 3 years of 365 days and the fourth year containing 366 days, and that the year should begin on the first of January.

See Also

► Clocks and Watches
► Sexagesimal System

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Calendars in India

A. K. Chakravarty

Calendrical science developed in India in three distinct phases, and each phase influenced the succeeding one. The first phase produced the Vedic calendar, covering a period from an unknown antiquity to the Mauryan emperor Aśoka (ca. 300 BCE); the second had the Greco-Indian calendar for a short period between the post-Aśokan and post-Kuṣāṇa period (ca. AD 300). And the third produced the Siddhāntic calendar from the Gupta period (AD 319) which is still used in India today. All three phases are characterized by formulations of fitting a lunar year into a sidereal solar one by suitably intercalating lunations.

References to calendrical elements like lunation, intercalation, year, and solstice occur even in the earliest part of Vedic literature. A separate calendrical literature, deemed a part of the Vedas, was developed in a small text, *Vedāṇga Jyotiṣa*, but this text has not been fully deciphered yet. There are some astronomical statements in the text, and also in the earliest part of Vedic literature, which do not hold true in the latitude belt and in the time period when the Vedic Aryans are believed to have settled in India.

It is a separate course of study as to how and when the Vedic Indians obtained this calendar, but they adopted it without verifying it.

This calendar is based on the following imperfect parameters:

- Five sidereal years = 1,830 days
- Sixty two lunations = 1,830 days
- Sixty seven sidereal lunar months = 1,830 days

The star *beta Delphini* indicates the winter solstice (which was indeed the case around 1500 BCE) which is apparently a fixed point. The lunar orbit is divided into 27 equal arcs from *beta Delphini* each equal to 13°20′, called *nakṣatra*, the first arc named *Dhaniṣṭhā*. The arcs are named after a prominent star of the division. The theory is that if, in 5 years, two lunations are intercalated, then the lunar year will remain tied with the solar one. This period is called a 5-yearly cycle or *yuga*.

In practice, a cycle begins when the sun and the moon are in conjunction at *beta Delphini* (i.e., from the winter solstice). The first, second and fourth year each contain 12 new moon ending lunations. One lunation is intercalated at the middle of the third year and another at the end of the fifth. The second cycle then again begins from a similar new moon at winter, solstice.

This imperfect calendar was destined to collapse, as the succeeding cycles will begin from new moons shifted by some 4.5 days from the winter solstice at *beta Delphini* per cycle, accumulating to one lunation in six or seven cycles. However, the calendar did not collapse, and so the accumulated lunation was extracalated, but we are not told in the text how this was done. Perhaps the rule is hidden in an obscure part of the text, and so we have to guess it.

A lunation is divided into 30 parts called *tithis*. Accordingly, 30 *tithis* = 1,830/62 days. The excess 30/62 of a *tithi* over a day is called an omitted *tithi*. A month's days are designated by the *tithi* of the day and not by ordinal numbers. The Jainas used this cycle in their calendar with a marginal change: that months were full-moon-ending and a cycle began from a full moon at summer solstice in the middle of the *Āśleṣā* division (180° away from *beta Delphini*).

Kautilya wrote a book entitled *Arthaśāstra* which is believed to reflect the social and administrative conventions of the Mauryan empire. This book, on the subject of measuring time, only reproduced the Jain school of the 5-yearly cycle. We are thus assured of its use until then.

The second phase of the Indian calendar began by the first century BCE after Śaka penetration into northwestern India.

The Śakas, a central Asian people, conquered Bactria in 123 BCE and established an era with epoch at 123 BCE, now called the Old Śaka Era. This epoch has variously been fixed at 88 BCE (Konow) and 110 BCE (Herzfeld), but, as M.N. Saha has shown, 123 BCE fits into all the circumstantial evidence.

The Śakas used the Greek calendar based on the Metonic cycle in their homeland. This was a 19 year cycle at whose beginning and end the sun and moon are in the same relative position to each other. When they reached India they adopted Indian culture and Aryanized or Indianized the Greek calendar, producing a Greco-Indian calendar. It replaced the classical 5-yearly cycle and it circulated in India up to ca. AD 200. The Kuṣāṇas, another Śaka tribe, penetrated further inside India, adopting Indian culture and using this calendar. Kings of the Śaka and Kuṣāṇa dynasties left behind some inscriptions bearing dates. These always refer to an era, as in era of king Kaṇiṣka. Further, they contain a mysterious expression – *etaye purvam* – whose meaning has not been deciphered.

The Indian form of the calendar is that the months are full moon ending; the 19-year cycle begins from a full moon at the autumnal equinox in the month Kārtika; months are assigned Sanskrit or Sanskritized Greek names; and, in special cases, the day is designated by the moon's *nakṣatra* on that day. The Greek form is that days are designated by ordinal numbers and not by *tithis*, and intercalation is made at the middle of the year in Chaitra.

All these features are fully reflected in the inscriptions of the Kuṣāṇa kings. For example, present researches have shown that Kaṇiṣka established his era in AD 78 after deleting the 100th place in the old Śaka era for that year.

Now, 123 + 78 = 201 = 1, deleting the hundredth place. Hence, AD 78 = 1 Kaṇiṣka era (current) and 0 Kaṇiṣka era (elapsed).

We interpret *etaye purvam* as elapsed year, and accordingly the Julian equivalent of Kaṇiṣka era in these inscriptions is:

$$\text{AD}\,78 = 0\,\text{Kaṅiṡka era.}$$

The day of the month can also be identified with the *tithi* with tolerable accuracy. We have seen that the moon gains 12° over the sun per *tithi*. In case of new-moon-ending months, we should expect, on 20th Āṣāḍha:

- Moon – sun = 20 × 12° = 240° (near about)
- Or sun = moon – 240°.

If the moon is near *Uttara Phalguni* (tropical longitude in AD 90 = 144°46′), we should have: sun = 144°46′–240° = 265° (say), so that the sun's position comes near the winter solstice, which cannot happen in Āṣāḍha. However, if the month is full-moon-ending, then the moon-sun = 5 × 12° = 60°, or sun = moon – 60° = 144°46′−60° = 85° (say), i.e., near the summer solstice, which indeed happens in Āṣāḍha.

If we compute the mean tropical longitude of the sun (L) and mean elongation of the moon in days (D), we get (Table 1):

These lunisolar positions are in complete agreement with the inscriptional dates. We may perhaps identify these dates as Julian equivalents of the inscriptional dates. Using this scale we can decipher all the other dates in the inscriptions of the Kuṣāṇa kings and use the same method to decipher the dates of the old Śaka Era.

This second phase was short-lived, but had far-reaching effects on the later Indian calendar. In fact, this was perhaps the most productive period in Indian calendrical history.

Calendars in India, Table 1 In a period of 4,320,000 years

Date	L	D
June 21, AD 90	87°.16	4.81

This Greco-Indian calendar was discontinued after the fall of the Kuṣāṇa empire.

In the third phase, the Indian calendar was thoroughly revised. New calendrical elements were introduced, new techniques in computational works were formulated, and the application of cycles for intercalation was abandoned. The new calendar that emerged is called the Siddhāntic calendar. This calendar was perfected by later Indian astronomers and is still used all over India with some marginal changes in some regions. In this phase the solar zodiac with 12 signs was introduced. The *nakṣatra* division was recast so that the first arc-division, renamed *Aśvinī*, began from the first sign *Meṣa* (Aries). This common point was the vernal equinox. By AD 550, the vernal equinox shifted to *zeta Piscium*, and this star (or a point very close to it) has since been the beginning of the Indian zodiac.

The new technique for computations was that an epoch, *Kaliyuga*, was formulated such that all the luminaries, like the sun, moon, and planets, were assumed to be in conjunction at the initial point of the zodiac at this epoch. Sidereal motions of the luminaries were so assigned that each of them made an integral number of revolutions in a period of 4,320,000 years (see Table 2).

Astronomical parameters in this phase were not uniform in different schools. We cite below some calendrical parameters from the Āryabhaṭian school (AD 476) and the *Sūryasiddhānta* school of the tenth century.

For any day in question, elapsed days from Kali are computed from the above figures, and from the rates of sidereal motion of the luminaries their positions are found in the zodiac. The epoch of *Kali* was computed by Bentley at 18th February, 3102 BCE midnight at Ujjain (longitude 75°45′ east). This date has been generally accepted by all astronomers.

► Āryabhaṭa formulated corrections of mean motions of the luminaries, but such formulations are not found in earlier works. Our presumption is that only mean motions were considered in the pre-Āryabhaṭian period.

In this revised calendar, the luni-solar year begins from the new moon just preceding the sun's entry to the initial point in the spring month *Chaitra*. Now, 12 lunations fall short of 10.8 days from a sidereal year, and this accumulates to one lunation in 2 or 3 years. Whenever such an extra lunation forms, it is intercalated in the year; there is no role of any cycle here. This luni-solar year, with days designated by the *tithi* of the day, is used all over India for religious purposes.

Calendars in India, Table 2 In a period of 4,320,000 years

	Āryabhaṭa	*Sūryasiddānta*
Sidereal revolution of the sun	4,320,000	4,320,000
Sidereal revolution of the moon	57,753,336	57,753,336
Sidereal revolution of Jupiter	364,224	364,220
Total civil days	1,577,917,500	1,577,917,828
Intercalary lunations	1,593,336	1,593,336
Omitted *tithis*	25,082,580	25,082,252

A solar year is also devised beginning from the sun's entry into the first sign *Meṣa*, and is divided into 12 solar months, each month being the period the sun stays in a sign. Days of solar months are designated by ordinal numbers. The first month is *Vaiśākha*. Datings are recorded by luni-solar year in some regions, and by solar year elsewhere. The era generally used is the Kaṇiṣka era renamed the Śaka era.

In a year containing 12 lunations, the 12 new moons will, most generally, be distributed over the 12 signs, i.e., each sign will contain a new moon. However, in an intercalary year when 13 lunations are distributed over 12 signs, 2 new moons must occur in 1 sign, and in extreme cases, 1 sign may not contain any new moon at all. Such situations are natural phenomena and are no problem for astronomers.

Out of the 13 lunations occurring in an intercalated year, any one may be earmarked as the extra month. However, metaphysics has taken a toll here. As one sign will contain two new moons, so two lunations, one from each new moon, will occur in that sign. One lunation out of these two has to be selected as the intercalary

one. Volumes of religious literature have been written, perhaps more voluminous than their astronomical counterparts, on which lunation is the proper one and which is the intercalary one. Similarly, when a sign becomes void of a new moon, religious literature is controversial as to which lunation is to be assigned to that sign. Almost every region of India has its own convention on these points.

See Also

► Astrology in India
► Astronomy
► Lunar Mansions in Islam

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Calendars in Islam

Mohammad Ilyas

Even the most ancient peoples considered the day the earliest unit of time-telling. However, the day is not convenient for long intervals of time. Even allowing for a primitive lifespan of 36 years, a person would live some 13,500 days, and it is very easy to lose track of some of those.

It seems natural to turn to the Earth's next most prominent body, the moon, for another unit. Here, the readymade period of the lunar phases provides the natural unit called the *lunar month*. The lunar month is approximately 29.5 days (more exactly 29.5306 or 29:12:2.8). In pre-agricultural times, the month provided a convenient and simple method for measuring moderately long periods of time. A lifetime of something like 400 months is a more convenient figure than 13,500 days. Lunar months united to the seasons, as they would have been initially, would produce some problems for a settled agricultural society, which is not the case for a hunting or herding society of nomads, who could wander more freely in search of grain or grass. Farmers not only had to stay where they were, but also needed to increase their chances of a good harvest by sowing at a proper time to take advantage of seasonal rains and seasonal warmth. Therefore, to keep the lunar months approximately seasonal, an intercalary month needed to be added in 7 of each 19-year cycle (19 solar years = 235 lunar months, i.e. 19 lunar years of 12 months each, +7 lunar months). In due course, the practice of intercalation was gradually perfected; the intercalary months came to be added in the 3rd, 6th, 8th, 11th, 14th, 17th, and 19th year of each cycle, in a popular scheme which transformed the lunar calendar into a seasonal, or lunisolar calendar, in which a month remained in pace with the sun to within 20 days.

The lunisolar calendar practice was adopted by the Hebrews, Greeks, and Romans and remains in use in the Jewish, Hindu, and Chinese calendars of today. The early Christians continued to use the Jewish (lunisolar) calendar tied to the new moon for more than three centuries and established the day of Easter on that basis. On the other hand, the Roman Republic, which had also used a lunisolar calendar for a long period, moved to a purely solar calendar in 46 BCE as a result of abuse of power by Pontiffs in the matter of intercalation.

Julius Caesar decided to put an end to this chaotic situation by introducing the solar calendar system. In this transformation, 46 BCE was allowed to continue for 445 days (!) and came to be known as "The Year of Confusion", in effect the last one. The adopted solar calendar with a year length of 365.25 days became known as the Julian calendar.

The month, being tied to the moon, begins at a fixed phase in the lunar calendrical system. Since any phase will do, the month can begin at each full moon, the first quarter, etc. However, the obvious way is to begin each month with the new moon – on the evening when the growing crescent first becomes visible immediately after sunset. Practically all lunar calendars began their new months with the new visible crescent. Some modern users of the lunar calendar (the Chinese and Jews) have changed this to the astronomical new moon, i.e. the conjunction, while Muslims maintain the first visible phase of the new crescent as the beginning of a new month.

The Islamic calendar was both a religious as well as a civil calendar, necessary to determine periods of the annual month-long fast, pilgrimages, times of marriage and divorce, years of taxes on wealth for the needy, religious observances, and general and historical timekeeping.

In Arabia, the use of a lunar calendar is known to have existed from very early times. The original practice is believed to have been to use 12 lunar months to a year. On the pre-Islamic Arab calendar, the annual Pilgrimage (*Ḥajj*) to *Kaʿbah* in Mecca was a most significant and important event. Although the event of the pilgrimage to *Kaʿbah* was basically religious, it was also important for trade and business. When the *Ḥajj* was out of season, it created difficulties in procuring the crops and sacrificial animals for trade and use. To overcome this, the Arabs in Mecca are believed to have introduced a system of intercalation known as *al-Naasi*. A Meccan by the name of Qalmas is reported to be the first person assigned this task who, during each pilgrimage, would announce the dates for the coming years' *Ḥajj* and inform whether the intercalation was due for the coming *Ḥajj* season.

In addition to the month of *Dhu'l-Hijjah* (in which the pilgrimage is held), three other months (*Rajab*, *Shawwal*, and *Thu'I Qa'dah*) were sacred to the pre-Islamic Arabs. During these months, certain things, such as wars with opponents, were forbidden. In time, the practice of intercalation was much abused (as with the Roman calendar) thus affecting the sacred months and the related prohibitions by changing a sacred month into a non-sacred one.

The calendar in use in Medina (North of Mecca) remained in the original "twelve months to a year" form. The early Muslims continued to use the Meccan calendar while in Mecca, but shifted to the *Medinan* calendar after the Prophet Muḥammad and his companions migrated to Medina in AD 622. Following the conquest of Mecca in the eighth year of *Hijrah* (December AD 629), the Muslims continued to use the Medinan calendar, and the *Meccan* calendar ran parallel.

However, during the Prophet Muḥammad's last pilgrimage in the tenth year of *Hijrah* (AD 632), the Meccan practice of intercalation was abolished through a Quranic injunction, thus reverting the Arab-Islamic calendar to the simple "twelve months to a year" practice.

The Islamic calendar also required that the beginning of a month be based on the first sighting. This was particularly important for religious events like the beginning and end of the fasting month and the date of the pilgrimage to the *Kaʿbah*.

There was no commonly accepted permanent calendar in pre-Islamic Arabia. Nevertheless, the custom of counting years was, in one form or another, prevalent among the Arabs and their neighbours. Opinions are divided as to the origin of this practice. According to Ibn al-Jazwī, it dates from the time when the children of the prophet Adam multiplied and spread on earth. In South Arabia, a calendar system originated in 115 or 109 BCE when the Himyarites adopted one using the reigns of the Tubba as the epoch years of their era. The inhabitants of Sanaa (Yemen) also adopted a calendar, using the victory over the Yemen by the Abyssinians, and later, the Persian conquest.

The origin of a chronology of events in North Arabia may be traced as far back as the construction of the *Kaʿbah* by the prophet Abraham and his son the prophet Ismail. The northern Arabians are also reported to have their famous battle days as marking epochs of eras. A local calendar is supposed to have existed in Medina also. Al-Masudi maintains that the people of Medina used the dates of their castles and palaces as their local calendar at the time of the prophet Muḥammad's migration, but others reject this, claiming the adoption of an era by the people of Medina to a month or two after the prophet's arrival, which continued until his death in AD 632. According to a widely held view, the *Hijrah* era was set up at the time of Caliph ʿUmar ibn Khattab in AD 637/638, i.e. about 5 or 6 years after the introduction of the purely lunar calendar. After many consultations, the year of the prophet Muḥammad's *Hijrah* was accepted for the beginning of the Islamic (or *Hijrah*) calendar.

Based on scientific understanding, certain ground rules were laid down which form the part of *sharīʿah* (the Islamic legal system) governing the calendar. Some of these were:

1. The length of a month should be 29 or 30 days.
2. The length of a year should be 354 or 355 days.
3. The maximum number of consecutive 30-day months is 4; the maximum number of consecutive 29-day months is 3.
4. Each new month begins with the first light of the new crescent moon visible on the western horizon after sunset.
5. One should try sighting the new moon on the 29th day of the month, but if it cannot be seen (even due to clouds), complete the month as of 30 days.
6. The visual sighting report must be corroborated by a witness.
7. The persons involved in the reporting must be reliable, adult, truthful, and sane, with good eyesight (implied). They are punished if proved to be purposely misleading.
8. The visual sighting report should not conflict with basic scientific understanding and natural laws. Indeed, professional scientists' involvement is essential to ascertain the reliability of the reported sighting, and the scientific test would include a check on related parameters (e.g. the shape of the crescent, its position and altitude, time of observation, sky conditions).
9. The sighting must be carried out in an organized way every month.

Sharīʿah also allows for the correction of a mistake. If on the 28th day of an Islamic month, the new moon has been sighted, a correction will be made to the beginning of the month, since a month should have only 29 or 30 days. If the month concerned is *Ramaḍan* then an extra fast would have to be completed after Eid celebrations.

Clearly, earliest visibility of the new moon plays a very critical role in Islamic calendar regulation. The Islamic "State" placed special emphasis on astronomy research, and it became a standard element in formal religious and legal education. The early Muslim community, based under the clear skies of Arabia and assisted by State-sponsored research, had no serious problems in following these injunctions to regulate their calendar. Muslims contributed enormously to the development of the science of the new Moon's earliest visibility and its advance prediction for greatly varying geo-environmental situations. In this, they built upon the work of earlier researchers as well (e.g. Babylonians, Hindus,

Jews). Besides the rigorous science, simple schemes were devised to construct long-term calendars especially to interconvert Islamic dates with Christian and other lunisolar calendrical dates. Based on technical information, one of the simple schemes (known as the schematic or *Istalahi* system) involved a cycle of 30 lunar years in which months approximately alternate between 29 and 30 days and 11 years consist of 355 days, the rest 354.

Backed by extensive research, Muslim scientists developed visibility tables and produced many reference works. All were well when astronomy and scientific endeavour were at their zenith in the Muslim lands.

Scientific interest in predicting the time of the first (earliest) new Moon sighting (for a clear sky) goes back to a period at least as early as the Babylonian era. Based on careful observational data, a simple criterion was developed and passed on to the Muslims through the Hindus, apparently with very little further improvement. This problem was thoroughly investigated by the early Muslim astronomers in the eight to tenth centuries AD and included such notable persons as ►Ḥabash al-Ḥāsib and ►al-Battānī. The physics-based system(s), developed up to the eleventh century, saw very little further development until more recent times, when improvements were made. There has also been a series of simpler criteria involving time difference (lag) between moonset and sunset and the "age" of the moon.

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Calendars in Mesoamerica

Tom Jones

For many reasonably educated persons, the greatest single achievement of ancient Mesoamerica was the Maya calendar. In fact, a calendar was in use throughout Middle America, but it is its Maya form that has captured the world's imagination, the claim often being made that its accuracy exceeded that of the calendar in use in Europe at the time of the Conquest and, by some, even of that which we use today. While most of their neighbors kept account of time with three periods of differing numbers of days, the combinations of which formed a repeating calendar of 18,980 days, the Maya employed a mechanism that synchronized these same periods and others of their own making with a system that tracked cumulative time.

This cumulative record, or ►Long Count, expressed historical dates with five-place numbers that recorded days accumulated from an arbitrary zero-point which has been determined to correspond to August 13, 3114 BCE in our present Gregorian calendar. (The correlation of Maya dates to European are to the no-zero-year Gregorian calendar, employing Thompson's 1935 correlation of 584,285 days.) Accumulating 1-day (*k'in*), 20-day (*winal*), and 360-day (*tun*)

PLACE	NAME	DAYS	CALC	VALUE	GLYPHS
1	*K'in*	1 day	(1 X 1)	1 *K'in*	
2	*Winal*	20 days	(20 X 1)	20 *K'inob*	
3	*Tun*	360 days	(18 X 20)	18 *Winalob*	
4	*K'atun*	7200 days	(20 X 360)	20 *K'atunob*	
5	*Bak'tun*	144,000 days	(20 X 7200)	20 *Bak'tunob*	

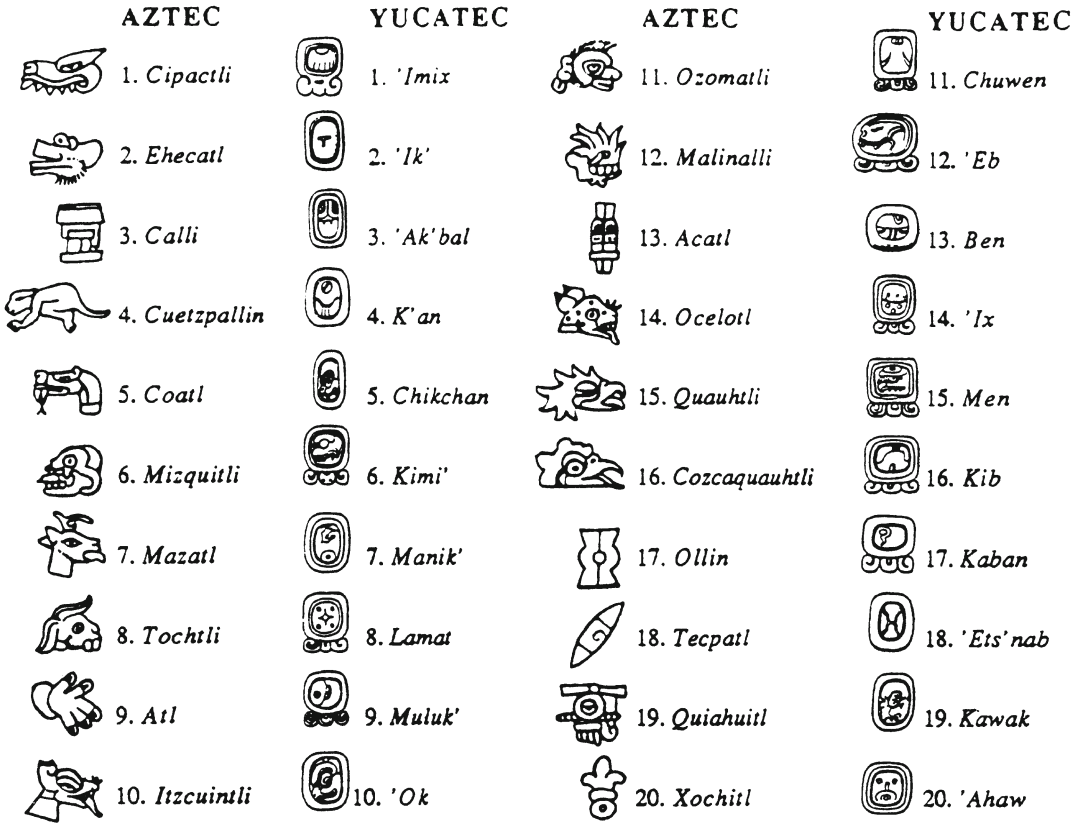
Calendars in Mesoamerica, Fig. 1 The names and values of the Long Count places with their respective glyphs (Drawings by the author)

periods, the Long Count employed a qualified vigesimal (20-base) place-number system – the qualification being an 18-base for the third place. The names and values of the Long Count places, from the unit up, were expressed in the writing system with distinct hieroglyphs for each order of magnitude (Fig. 1).

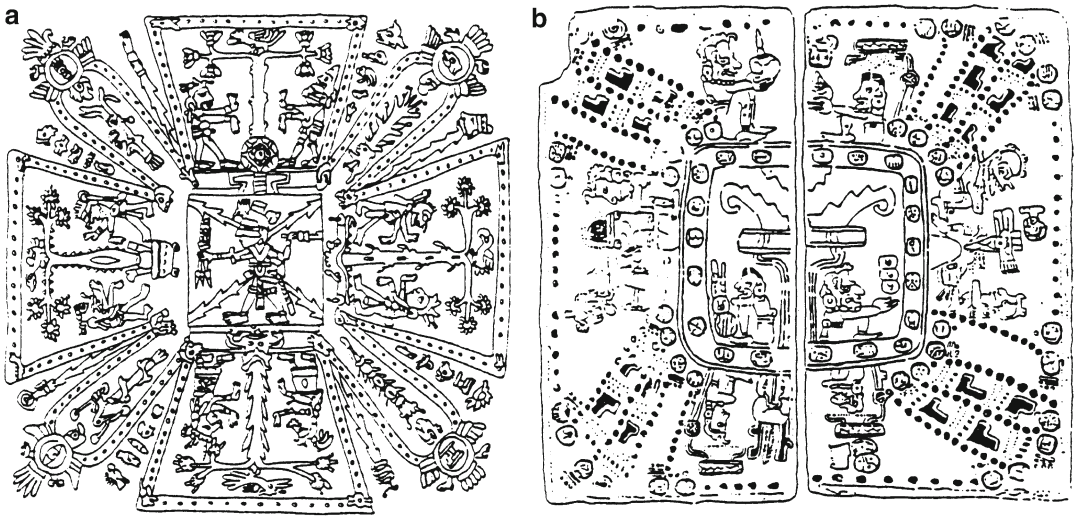
Thus, for example, a Long Count date with the numerical value of *9 bak'tunob, 8 k'atunob, 9 tunob, 13 winalob*, and *0 k'inob* records a day that was 1,357,100 days after August 13, 3114 BCE, which is to say March 26, 603. These values were communicated by positioning the numbers as prefixes or superfixes of the glyphs for the periods. The *-ob* inflection of Mayan nouns indicates plural. Because double digits are often required to express decimal equivalents of numbers in the places of the Maya system, Mayanists have adopted the convention of inserting periods between the places of Long Count dates. The above date, for example, is written 9.8.9.13.0. Though Maya historical dates that employed the Long Count were generally limited to five places, the calendrical system itself was open-ended and, when called upon to do so (as to meet mythological needs) could accommodate any number of places and express any full number of days. The greatest known to have survived is recorded at Coba as 13.13.13.13.13.13.13.13.13.13.13.13.0.0.0.0.0, which expressed in our decimal-system amounts to almost 22 quintillion tropical years!

Long Count dates were carved on monuments in the Maya heartland for over 600 years, the earliest known being 8.12.14.8.15 (8 July 292), the latest 10.4.0.0.0. (20 January 909). Moreover, the *Dresden Codex* records the much later date, 10.17.13.12.12 (29 October 1178). Though extensively used by the Maya, the Long Count was probably not their invention. Earlier Long Count dates have survived on several monuments on the southwestern Maya periphery – the earliest, 7.16.3.2.12 (7 December 36 BCE), at Chiapa de Corzo – in what was probably a proto-Zoquean (non-Mayan) speaking area.

The Maya coordinated this cumulative Long Count with the pan-Mesoamerican repeating calendar of 18,980 days. Known generally as the Calendar Round and called the *xiuhmolpilli* by the Aztecs and *hunab* by the Maya, this period consisted of three component cycles of 13, 20, and 365 days. The first two of these were a set of consecutive day-numbers (1–13) and a set of 20 day-names specific to each of some 60 language-groups within Mesoamerica (Fig. 2). The permutations of the 13 numbers and 20 names designated each passing day with a combination that repeated every 260 (13 × 20) days. This resulting 260-day period was termed the *tonalpohualli* by the Aztecs and is called the *tsolk'in* by Mayanists. Mesoamericans visualized this period as a four-sided cosmogram (Fig. 3) that can be described as a "Maltese" cross (the broad arms of which are identified in a counterclockwise order



Calendars in Mesoamerica, Fig. 2 The 20 Aztec (Nahuatl) and Yucatec (Mayan) day-names and signs (Drawings by the author)



Calendars in Mesoamerica, Fig. 3 The 260-day period as Portrayed by the (**a**) Aztecs in the *Fejervary-Mayer Codex* and (**b**) Maya in the *Madrid Codex*

YUCATEC	AZTEC	YUCATEC	AZTEC
1. *Pop*	1. *Tlaxochimaco*	10. *Yax*	10. *Izcalli*
2. *Wo'*	2. *Xocotlhuetzi*	11. *Sak*	11. *Atlcahualo*
3. *Sip*	3. *Ochpaniztli*	12. *Keh*	12. *Tlacaxipehualiztli*
4. *Sots*	4. *Teotleco*	13. *Mak*	13. *Tozoztontli*
5. *Sek*	5. *Tepeilhuitl*	14. *K'ank'in*	14. *Hueytozoztl*
6. *Xul*	6. *Quecholli*	15. *Muwan*	15. *Toxcatli*
7. *Yaxk'in*	7. *Penquetzaliztli*	16. *Pax*	16. *Etzalcualiztl*
8. *Mol*	8. *Atemoztli*	17. *K'ayab*	17. *Tecuilhuitontlii*
9. *Ch'en*	9. *Tititl*	18. *Kumk'uh*	18. *Hueytecuilhuitl*
		Wayeb	*Nemontemi*

Calendars in Mesoamerica, Fig. 4 The eighteen 20-day periods and final 5 days of the Aztec *xihuitl* and Maya *haab*

as East, North, West, and South) superimposed over a "St. Andrew's" cross (the narrow arms of which define the diagonal directions Northeast, Northwest, Southeast, and Southwest). The eight projecting arms of this scheme are each comprised of 13 days proceeding out from the center and 13 more returning, with the four outer edges of the "Maltese" arms also each contributing 13 to complete the round of 260 days. This 260-day *tonalpohualli* was the most significant aspect of the calendar for the daily life of the typical Mesoamerican. It formed the basis of numerous rituals, character evaluations, omens, and prognostications, traced out in Aztec, Mixtec, and Maya books.

While the 260-day ritual period seems to have been the result of the combination of a cultural fascination with the number 13 and a vigesimal counting system derived from the number of digits of the hands and feet, the 365-day period – the Maya *haab* or Aztec *xihuitl* – to which we now turn, was an attempt at a full-number approximation of the tropical year (of 365.2422 days, as calculated today). This "vague year" was achieved by a set of 18 named periods of 20 consecutively numbered days each, and five extra consecutively numbered terminal days (*Nemontemi* in Aztec, *Wayeb* in Maya) to total 365 days ($18 \times 20 + 5$) (Fig. 4). Every day, then, could be expressed with a day-number, a day-name and a numbered position in one of the periods of the "vague year." The workings of this Calendar Round system are well illustrated by comparing the modes of expressing succeeding dates that include the five terminal days of the vague year in the Aztec *xiuhmolpilli* and Maya *hunab* (Fig. 5). The presence of these 5 days causes the position of any given *tsolk'in* day to drop back by 5 days with each successive vague year. Because 260 and 365 share a common denominator of 5, any specific combination of day-number, day-name, and vague year position repeats every 18,980 days ($260 \times 365 - 5 = 18{,}980$), or about 13 days short of 52 tropical years. As with the ▶ Long Count, evidence for the origins of the Calendar Round lies beyond the western pale of the Maya, dating from as early as the sixth century BCE in the Zapotec region.

The *xiuhmolpilli* was of particular importance to the Aztecs, whose mythology claimed that the age in which they lived and in which the current Sun-God, *Tonatiuh*, reigned was preceded by four earlier ages, each with its own sun and each of which had been destroyed in its own way – the first by devouring jaguars, the second by winds, the third by a rain of fire and the fourth by a world-flood. During this fifth era, under *Tonatiuh*, the future seems to have been doled out to the Aztecs one *xiuhmolpilli* at a time. Each successive *xiuhmolpilli* had to be freshly solicited by a great deal of bloodletting and an elaborate "New Fire" ceremony that was carried out during the five *Nemontemi* days of each 52 *xihuitl*. If, following the ceremony, the stars continued on

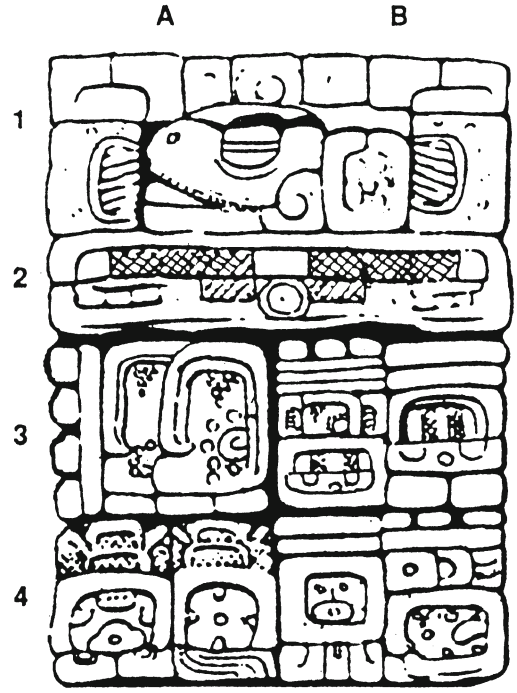
Calendars in Mesoamerica, Fig. 5 The succession of 25 Calendar Round dates that pass through the five terminal days of the *xihuitl* of the Aztec *xiuhmolpilli* and the *haab* of the Maya hunab

AZTEC		MAYA	
XIUHMOLPILLI		*HUNAB*	
TONALPOHUALLI	*XIHUITL*	*TSOL K'IN*	*HAAB*
1. *1 Cipactli*	*14 Huetecuilhuitl*	1. *1 'Imix*	*14 Kumk'u*
2. *2 Ehecatl*	*15 Huetecuilhuitl*	2. *2 'Ik'*	*15 Kumk'u*
3. *3 Calli*	*16 Huetecuilhuitl*	3. *3 'Ak'bal*	*16 Kumk'u*
4. *4 Cuetzpallin*	*17 Huetecuilhuitl*	4. *4 K'an*	*17 Kumk'u*
5. *5 Coatl*	*18 Huetecuilhuitl*	5. *5 Chikchan*	*18 Kumk'u*
6. *6 Mizquitli*	*19 Huetecuilhuitl*	6. *6 Kimi*	*19 Kumk'u*
7. *7 Mazatl*	*20 Huetecuilhuitl*	7. *7 Manik'*	*20 Kumk'u (0 Wayeb)*
8. *8 Tochtli*	*1 Nemontemi*	8. *8 Lamat*	*1 Wayeb*
9. *9 Atl*	*2 Nemontemi*	9. *9 Muluk*	*2 Wayeb*
10. *10 Itzcuintli*	*3 Nemontemi*	10. *10 'Ok*	*3 Wayeb*
11. *11 Ozomatli*	*4 Nemontemi*	11. *11 Chuwen*	*4 Wayeb*
12. *12 Malinalli*	*5 Nemontemi*	12. *12 'Eb*	*5 Wayeb (0 Pop)*
13. *13 Acatl*	*1 Tlaxochimaco*	13. *13 Ben*	*1 Pop*
14. *1 Ocelotl*	*2 Tlaxochimaco*	14. *1 'Ix*	*2 Pop*
15. *2 Quauhtli*	*3 Tlaxochimaco*	15. *2 Men*	*3 Pop*
16. *3 Cozcaquauhtli*	*4 Tlaxochimaco*	16. *3 Kib*	*4 Pop*
17. *4 Ollin*	*5 Tlaxochimaco*	17. *4 Kaban*	*5 Pop*
18. *5 Tecpatl*	*6 Tlaxochimaco*	18. *5 'Ets'nab*	*6 Pop*
19. *6 Quiahuitl*	*7 Tlaxochimaco*	19. *6 Kawak*	*7 Pop*
20. *7 Xochitl*	*8 Tlaxochimaco*	20. *7 'Ahaw*	*8 Pop*
21. *8 Cipactli*	*9 Tlaxochimaco*	21. *8 'Imix*	*9 Pop*
22. *9 Ehecatl*	*10 Tlaxochimaco*	22. *9 'Ik'*	*10 Pop*
23. *10 Calli*	*11 Tlaxochimaco*	23. *10 'Ak'bal*	*11 Pop*
24. *11 Cuetzpallin*	*12 Tlaxochimaco*	24. *11 K'an*	*12 Pop*
25. *12 Coatl*	*13 Tlaxochimaco*	25. *12 Chikchan*	*13 Pop*

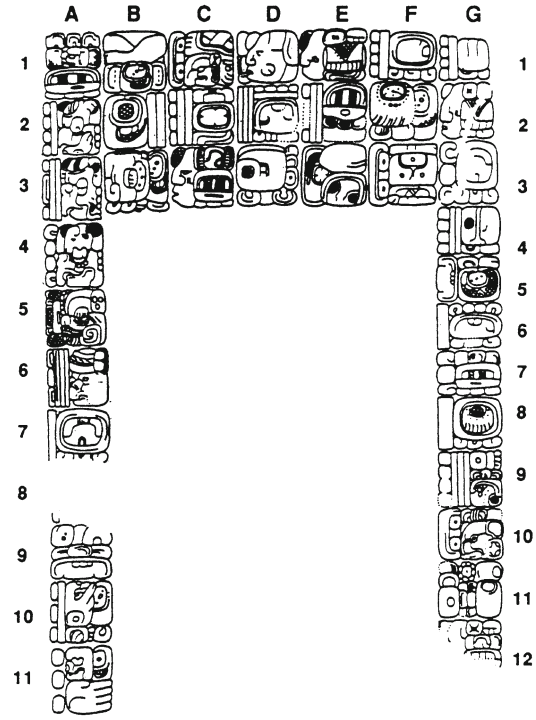
their steady march across the midnight-sky of the last day of the *xiuhmolpilli* – presumably because the gods had found the ritual to their satisfaction – the people could be assured that another 52 "years" had been granted them.

In the Maya region, this endlessly repeating pan-Mesoamerican cycle was synchronized with the accumulated days of the Long Count as the mathematical consequence of the arbitrary assignment of the Calendar Round date *4 'Ahaw 8 Kumk'u* to the Long Count zero-date (13 August 3114 BCE). Written out in full and preceded by a distinctive hieroglyph that served to introduce them, dates so synchronized stood at the very beginning of the hieroglyphic texts on the carved monuments of Mayadom – whence their designation, Initial Series dates. To take an example, the Initial Series date on Quirigua Stela I (Fig. 6) – which reads in typical Maya fashion, from top-left to bottom-right, two columns at a time – displays a large initial series introductory glyph (ISIG) in the initial position (A1–B2) followed by the Long Count *9.18.10.0.0* (A3–A4) and the Calendar Round *10'Ahaw 8 Sak* (B4), establishing a date corresponding to August 19, 800. (Glyphs are conventionally located by assigning upper-case letters to the columns of a text, numbers to its rows, and lower-case letters to divisions within the glyph-blocks and designating them in that order, as A3, C2a, F7b, etc. Number-values are dots for 1, bars for 5, and various special symbols for 0.

At times, supplementary to the Long Count and Calendar Round and inserted parenthetically between the *tsolk'in* and *haab* entries, were glyphs that recorded additional cycles of 7 or 9 days duration, as well as certain lunar information. Supplementing the cycles mentioned, the Maya tracked one of 819 days – a product of three basic periods ($7 \times 9 \times 13$) – relating it to a 4-day cycle (which the Aztecs also recognized) that linked each day with one of the four cardinal directions and associated colors (East, red; North, white; West, black; South, white). On Piedras Negras Stela 1 (Fig. 7), for example, the ISIG (A1) is followed by the ▶Long Count *9.12.2.0.16* (A2–A6) and the *tsolk'in* position *5 Kib* (A7), while the *haab* position, *14 Yaxk'in*,



Calendars in Mesoamerica, Fig. 6 Quirigua, Stela I: hieroglyphic text with Initial Series date (Drawing after Annie Hunter. From *Biologia Centrali-Americana*, by Alfred P. Maudlsay, reprinted in 1974 by Milpatron publishing corp. Used with permission of the publisher)



Calendars in Mesoamerica, Fig. 7 Piedras Negras, Stela 1: heiroglyphic text (Drawing by John Montgomery)

does not appear until eight glyph-blocks later (C2). The intervening blocks include two that record the seventh position of the 9-day cycle (A8–A9), one that records the moon's age as 8 days (A10), another the moon's number as third in a set of six (A11), two that name the moon (B1–C1), and one that identifies it as a 31 month (B2). Following *14 Yaxk'in* are four noncalendrical glyphs (B3–E1) describing the event of the Initial Series date (July 7, 674).

When there was a need to record multiple dates, each new one (expressed as a Calendar Round date) was typically linked to its predecessor by what scholars call a Distance Number. The Distance Number employed the same place system as the Long Count, but because the number of days to be recorded usually did not require all five places, they were entered in the reverse order of the Long Count – commencing with *k'inob* and proceeding only through those higher places necessary to record the distance. Thus on the Piedras Negras stela, following the initial event, come two glyphs that record the Distance Number *15 k'inob, 9 winalob*, and *12 tunob* (D2–E2), then two more that indicate an advance of that distance forward in time (D3–E3), and finally, two glyphs that record the Calendar Round date, *9 Chuwen 9 K'ank'in*. The calendrical mathematics are:

9.12. 2. 0. 16	*5 Kib*	*14 Yaxk'in*	(July 7, 674)
+12. 9. 15			
9. 12. 14. 10. 11	*9 Chuwen*	*9 K'ank'in*	(November 16, 686)

After two noncalendrical glyphs (F2–G2) that describe the event of the date so reached, come a second Distance Number, *5 k'inob* (F3), and the resulting third Calendar Round date,

1 Kib 14 K'ank'in (G3–G4). The mathematics are:

9.12. 14. 10. 11	*9 Chuwen*	*9 K'ank'in*	(November 16, 686)
+5			
9. 12. 14. 10. 16	*1 Kib*	*14 K'ank'in*	(November 21, 686)

This new date is followed by the single glyph that describes the event (G5). Then come the Distance Number, *5 k'inob, 2 winalob*, and *1 k'atun* (G6–G7), a fourth Calendar Round date, *5 Imix 19 Sak* (G8–G9), and fourth event (G10–G12). This final calculation is:

9. 12. 14. 10. 16	Z*1 Kib*	*14 K'ank'in*	(November 21, 686)
+1. 0. 2. 5			
9. 13. 14. 13. 1	*1 Imix*	*19 Sak*	(September 23, 706)

As was the case for the second of these two monuments, the Maya often accompanied their calendrical entries with lunar data. From this propensity and from the structure of a Lunar Table in the *Dresden Codex*, it is clear that their concern was to anticipate eclipse-possible dates. Because eclipses (both lunar and solar) can only take place during a period of 18 days on either side of node-passage of the Moon over the path of the Sun, which occurs twice during a tropical year, the Maya grouped the months in semesters of six (and for corrective purposes, occasionally of five). In an attempt to approximate the Moon's 29.53059-day synodic period (as calculated today), they ascribed 29 and 30 days, alternately, to successive months, compensating for the gradual accumulation of excess time by introducing an extra 30-day month at predetermined intervals. One result was the *Dresden Codex* Lunar Table with its eclipse-period of 11,960 days, or just over 405 complete lunations. However, that excess time would be allowed to accumulate until after eight repetitions of the period (95,680 days), when the table could be adjusted to correspond more closely to the moon's position by subtracting 1 day. The mathematics behind this adjustment are: $29.53059 \times 405 = 11{,}959.88895$; $11{,}960 - 11{,}959.88895 = 0.11105$; $11{,}960 \times 8 = 95{,}680$; $11{,}959.88895 \times 8 = 95{,}679.116$; $95{,}680 - 95{,}679.116 = 0.884$, or 21.216 h. To further refine the Lunar Table's use, follow-up adjustments had to be made with succeeding repetitions of the cycle.

Though not central to the calendar itself, the planet Venus was nevertheless also a concern of Maya calendrical savants. Observations and calculations recorded in the inscribed monuments show that the Maya employed a 584-day period to predict culturally important points in the planet's synodic period. Both the Maya and the Aztecs assigned numerological significance to the correspondence between five of these Venus-periods and eight *haabs* ($5 \times 584 = 2{,}920$; $8 \times 365 = 2{,}920$). Also, in the *Dresden Codex* is an elaborate table that consists of 13 sets of five periods of 584 days, or 37,960 days. Here again, because of the discrepancy between the full number 584 and the actual synodic period of Venus (583.97 days, by modern measurements) and because of the added cultural requirement that the first heliacal rising of the planet should occur on the *tsolk'in* date *1'Ahaw*, an adjustment like that in the Lunar Table had to be made after several runs of the Venus Table.

The Mesoamerican calendar, if by no means invented by the Maya, nevertheless reached its most elaborate form at their hands. Tracking basic periods of 4, 7, 9, 13, 20, 365, and 584 days and greater periods that were the products of various combinations or lowest common multiples thereof – 260(13×20), 819($7 \times 9 \times 13$), 2,920 (8×365; 5×584), 3,276 ($4 \times 7 \times 9 \times 13$), 18,980 ($13 \times 20 \times 365$) and 37,960 ($13 \times 20 \times 365 \times 2 = 13 \times 5 \times 584$) days – and groupings of months of alternately 29 and 30 days in duration, they synchronized them all with the cumulative and open-ended ► Long Count that recorded every passing day from its original *4 'Ahaw 8 Kumk'u* zero-point. Where the European calendar intercalated extra days as a device for keeping its dates in close harmony with the seasons (the vernal equinox, for example, occurring always on or about March 22), the Mesoamerican calendar, even in its most refined (Maya) mechanism, simply ground out the 1-day intervals of its several parts, accumulating or repeating them endlessly and without

C

interruption, all of its components creeping gradually backwards through the seasons. It was thus impossible to identify a position in the tropical year by knowing a Calendar Round date. The first *4 'Ahaw 8 Kumk'u* fell on August 13, but the second fell 12 days earlier on August 1 and the third, 12 more on July 19. In the year 265, near the beginning of the Classic Period, after having returned to its original August 13 date 113 times, *4 'Ahaw 8 Kumk'u* fell on May 16, and by the close of the Classic in the late ninth century, it had fallen back to December 15.

However skillfully the Maya may have combined their astronomical observations with calendrical calculations to predict lunar and solar eclipse stations, heliacal risings and settings, conjunctions, stationary points, and retrograde motions of the five visible planets, the fact remains that, for all its reputation, the calendar itself was no more accurate than the 365-day calendar the ancient Egyptians adopted around 4250 BCE which was the product of 12 30-day months ($12 \times 30 = 360$), plus – like the Mesoamerican *xihuitl* or *haab* – 5 extra days. Indeed, it was an Egyptian mathematician, Sosigenes, who, recognizing the faults of the rigid 365-day year, persuaded Julius Caesar to adopt his scheme for reforming the Roman calendar in 45 BCE, by intercalating an extra day every fourth year into an otherwise 365-day year. However, it would be unhistorical to judge the Maya calendar by a standard set by the Egyptian, the Julian, or the later Gregorian calendar. The cultural need of the Egyptians was to anticipate (for agricultural reasons) the annual flooding of the Nile. That of the Julian reform was to ensure that the Roman solsticial festival *fors fortuna* would fall regularly on June 22. The Christians, in turn, adopted the Julian calendar in 325 at the Council of Nicaea from a need to establish predictable dates for Easter, which – for religious reasons – had to fall on the first Sunday following the first full moon after the vernal equinox. It was this same need that led Pope Gregory XIII to authorize a further reform of the Julian calendar in 1582.

However, the cultural needs met by the Mesoamerican calendar were of a numerological-astrological nature. Quite apart from the divinations of the purely numerical *tsolk'in*, the Maya assigned significance to astronomical predictions based upon complex multiples of their several whole-number cycles which were often linked to the actions of remote or fabled ancestors or mythological supernaturals or to multiples of the never whole-numbered synodic periods of the heavenly bodies. Contrived calendrical calculations into the remote past and distant future were made to establish mythological beginnings, regenerations, and calamities to come. Day-to-day events, even to the timing of military attacks or battles among themselves or surrender to the Spanish, seem to have fallen under this numerological spell. However closely the *Dresden* Venus Table may appear to approach a modern astronomical ephemeris of Venus, its purpose was to return the latter's heliacal rising to *1'Ahaw*, the birth date of the mythological Venus-associated hero, *Hunahpu* – irrespective of any temporary losses in accuracy its mechanisms may have produced. If the calendrical efforts of Mesoamericans can be described as an attempt to bring about a marriage between their whole-number numerology and their perceived rhythms of the Sun, Moon, planets, and stars, it was one in which it was the latter who were to love, honor, and obey. However, if the test of a good marriage is its durability, then the Mesoamerican calendar – particularly in its Maya form – was not only mathematically sophisticated, conceptually elegant, and visually beautiful, but a highly successful one as well.

See Also

► Long Count
► Time

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Calendars in South America

R. Tom Zuidema

At the time of the Spanish conquest around the year 1530, the Incas had integrated different cultures, all belonging to Andean civilization, into a large empire, stretching from southern Colombia through Ecuador, Peru, and Bolivia, into northern Chile and Argentina. Much can be learned from the art of the Incas and their predecessors, including architecture, stone sculpture, pottery, and textiles. However, we have no access to written records as defined by western culture; understanding intellectual aspects of this civilization is almost exclusively dependent on what informants from Cuzco, the Inca capital in southern Peru, told the Spanish chroniclers. These were most impressed by Inca statecraft, although they were never present when it was still practiced. Their interpretation of Inca religion was heavily influenced by Christian opinions. Religion to them included memories of the Inca past and of state and private rituals related to, for instance, the calendrical organization of agriculture and llama husbandry. As Inca history is discussed in the article on ► Knowledge Systems of the Incas, this one concentrates on the calendar as it functioned in Cuzco.

Most of our information on the Inca calendar and related astronomical practices derives from only a few chroniclers: Juan de Betanzos [1551] (In case of an old text, square brackets indicate the date of writing or first publication), a soldier and the first chronicler to write on this subject in the context of a full account of Inca culture; an anonymous author [ca. 1565] with precise information on the integration of astronomical observations into the calendar; Cristóbal de Molina [1574], a priest with great knowledge of Inca rituals but excluding those for one-third of the year; and Bernabé Cobo [1653], a late Jesuit author who gave our most comprehensive description of Inca culture including the calendar for the whole year. His information probably derives from a now lost account by Juan Polo de Ondegardo [1559], whose own description of the calendar only survives in a much revised short version [1585] for use by Catholic priests. Later chroniclers and dictionaries mostly follow Polo's version and add little information toward a reconstruction of the original Inca calendar. This reconstruction provides very different results from the general picture that the chroniclers present us with.

All chroniclers conceive the Inca calendar as consisting of 12 months. Notwithstanding this agreement, there is much confusion about the nature of the months, their order, and their correspondence to Christian months. Some of this confusion may derive from much local variation among calendars in the empire, but most of the blame is due to Spanish misreporting on the Cuzco calendar itself. Betanzos, Polo, and Cobo describe a system of 12 "months" with a fixed position in the solar year. Molina speaks of "months" *and* "moons" and refers to rituals according to the phases of the moon for three times of the year, roughly corresponding to June, September, and January. Some modern scholars therefore argue that the whole calendar was lunar, but this was not the case (Ziólkowski and Sadowski, 1992). On each of the three occasions important lunar rituals were celebrated after an independent solar observation had been made for that time of the year. We have no information on lunar rituals in Cuzco for other times of the year; we can only conclude that the integration of solar and lunar rituals in Peru was done in a way different from Western (Christian, Jewish) presuppositions in this respect.

There are various difficulties in accepting the Inca organization of months according to the Polo version of 1585. For instance, two names are taken together for 1 month that in other versions refer to separate months; in other calendars a name may be used as an alternative for either one or a next month. In some versions, a month name is suppressed for no apparent reason at all; months were said to be of rather different lengths, either longer or shorter than 30 or 31 days. And the anonymous chronicler mentions for two double-months that the moon observed in 1 month (either the first or the second) would always reach the other, leaving us to conclude that the fixed double-month was shorter than two movable synodic (lunar) months $2 \times 29\frac{1}{2} = 59$ days. Comparing the various descriptions of the Inca year, it becomes clear that originally it contained 13 and not 12 months and that each version suppressed one or another month name to accommodate this calendar to the Spanish one. It may have been a goal of Catholic missionaries fighting against "pagan" rituals, but there was also Inca consent, realizing the advantages of combining Inca and Catholic celebrations, first openly and later secretly.

From indications by Molina and Cobo we can conclude that the Inca calendar placed 1 month around the June solstice (21 June), celebrating *Inti Raymi* (feast of the sun), and 2 months, *Capac Raymi* (royal feast) and *Capac Raymi Camay Quilla* (royal feast, feast of the moon) around the December solstice, which honored the fact that in the southern hemisphere the sun is strongest then. For practical reasons, *Inti Raymi* may have been celebrated not on the days of the June solstice but within its month during the full moon either before or after in a given year. People took advantage of the dry season's clear skies when the moon shone the whole night.

During *Capac Raymi*, considerations were different. While the June solstice marked the middle of a month, the December solstice, six and a half Inca months apart, marked the date separating the 2 months of *Capac Raymi*. Moreover, these months fell in the middle of the rainy season when normally no good observations of the sun and the moon could be made. The month of *Capac Raymi Camay Quilla* was celebrated, first awaiting the new moon with some celebrations. The major celebrations came with the next full moon and took some 7 days. If the new moon arrived early after the solstice (December 21), all celebrations took some 22 (15 + 7) days; but if it was late, they could take up some 52 (30 + 15 + 7) days. Then the full moon celebrations would not occur in *Camay Quilla* but extend into the next month. Although after those days the moon would still be visible late at night, no more attention would be paid. However, the day after these 52 days (February 13) was important for another reason. Then the sun in Cuzco – this city being $13\frac{1}{2}^{\circ}$ south of the equator and within the tropics – passes the zenith point in the sky at noon. Although the chroniclers were only vaguely aware of the importance of this event, Polo indicates that then a new year began, with people preparing for the coming harvest. The sun also passes the zenith 53 days before the December solstice, and we can assume that a similar calendrical calculation was made for this period. The anonymous chronicler considered it as one in which the moon of 1 month would always reach the other. Its beginning was celebrated with a feast, the *Itu*, which only Inca nobility could attend, and the last 6 days before the December solstice were also important for celebration. These days could begin with a full moon if the new moon had arrived late in this 53 day-period.

Apparently, the Incas divided the time from the first to the second passage of the sun through the zenith (107 days) into 4 months, of which the central ones of *Capac Raymi* were most important. The average length of the 13 months was about 28 days and as the connection to the length of a synodic month (29 days) was lost, there is no reason that the months could not be of various lengths as reported by the chroniclers. Having established the framework of the Inca calendar, an outline can be given of its ritual organization serving various, often contrasting, social needs.

The calendar organized, first, a multitude of sacrifices (llamas, guinea-pigs, birds, sometimes children) and offerings (mostly cultivated plants). The months were organized according to four seasons of 3 months and an independent

month after the sun's second zenith passage. Sacrifices and offerings expressed the different seasonal concerns.

A quite different organization of the months attended more political interests in terms of tribute due by Inca and non-Inca subjects and of the large feasts of state presented by the king, queen, and high nobility. In this organization, months were brought together in groups of two and then of four. This organization cross cut the seasonal one but kept the same independent month. Our first chroniclers mention how tribute was brought to Cuzco every 4 months and how non-Inca nobles accompanying these deliveries stayed for the same time in town. Betanzos adds to this that services of labor and distribution of food, especially meat and cloth, followed the same schedule. At first, the colonial administration showed interest in adopting this schedule for its own needs, but after about 1570 it changed to the European custom of having tribute paid twice a year, around Christmas and St John (24 June), and chroniclers no longer paid attention to the earlier system.

I mentioned above the most important 4 month-period around the December solstice. In between the times of planting and harvest, this was a season when the fields needed less attention and when heavy rainfall made travel difficult. *Capac Raymi* and its preceding month were dedicated to the initiation rituals of noble boys, these being assisted by noble girls who had had their own rituals of first menstruation at other times of the year. In the lunar rituals of *Camay Quilla* and the following month, noble men and women pledged their allegiance to the king, and rains were ritually dismissed awaiting the ripening of the fruits. In the 4 months around planting, land was first prepared for cultivation, ploughed and planted, and then rituals followed to help the budding plants grow and attract rains. Again, the two central months were dedicated to state rituals. First, the king himself helped with the planting. Keen observations were made of sunset throughout the first month to have the various timings for planting and irrigation of different sorts of plants, at lower, warmer and higher, colder places well orchestrated. In the second month, dedicated to the moon, the queen, and women in general, "evil" and "illnesses" were ritually driven out of town in support of peace among people and of the growth of plants. Finally, the 4 months of harvest included the early harvest, the general harvest around Cuzco, the reception of foreign lords with their presents and the tribute of their people, and storage. Again the most important ceremonies occurred in the central months when first harvest was ritually brought into town and then the Inca himself ploughed, opening a new agricultural year, and ate with all nobles and foreign lords in the plaza.

Good descriptions of Andean rituals were also made for the central provinces around Lima, the vice royal capital in colonial times, and some of these ceremonies can be compared with Incaic ones in Cuzco. But when those other records became available in the early seventeenth century, more than 80 years had already passed after the Spaniards had arrived in the Andes. Much research still has to be carried out making those comparisons fruitful for a reconstruction of pre-Hispanic calendars in general.

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Calendars in Turkey

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As a term, the word *takvim* (calendar) derived from the word "community," meaning to shape something, can be defined as a document that indicates the place of an event within a timescale that has a particular start point (Akgür, 2010, 487). Calendars are usually arranged in relation to the movements of the two main celestial bodies, the sun and the moon. An Islamic calendar known as the Hijri Calendar was used by the Ottoman Empire from its foundation to its collapse (1299–1923). It was established in the period of Prophet Omer, based on the 36th–37th verses from the Quran's *Surah at-Tawbah*. In the hadiths indicated, it is written that the number of moons under the reign of Allah is 12. In the hadiths, it is indicated that a month lasts 29 or 30 days.

In the Hijri Calendar, the Hijri of Prophet Muhammad marks the beginning of the calendar, and the first day of the first month, Muharram, marks the New Year. This calendar, known as Hijri-lunar, is equal to 1 lunar year, 354 days, 8 h, and 48 min. The lunar year is approximately 11 days less than the solar year that the Gregorian Calendar uses today. Therefore, 33.5 Hijri years are equal to 32.5 Gregorian years. In other words, once every 33.5 years, the Hijri Calendar gets 1 year ahead of the Gregorian Calendar (Akgür, 2010, 489). Along with this inadequacy of the Hijri Calendar, it has another negative feature which is that it fails to comply with the seasons which have great importance in agricultural life (BOA, MV, 199/186; *Tasvir-i Efkâr*, 14 Mart 1329).

In Ottoman fiscal tradition, treasury incomes used to be collected according to the solar year and the expenses were consumed according to the lunar year (Sahillioğlu, 228). This operation continued smoothly in the period when the income-expense balance was kept; the incomes collected were well spent, and the Ottoman army was ruled without spending the treasury income (*Takvimü'l-edvâr,* 52–53). Another phenomenon that reinforced the system was the continuous expansion of the borders and, therefore, the increase in public revenues (Gemici, 55). The day difference problem between the lunar and solar year was solved by skipping 1 year once in every 33 years, and the year skipped was known *sıvış yılı* (Tezâkir, 110; Nevsâl-i Millî, 8).

The dissolution faced in the Ottoman manorial system (*tımar sistemi*) disrupted the classical operation. In a period when the number of troops was increasing day by day, the salaries, which were paid four times a year, had become a great burden for the treasury. Moreover, the tax system that depended on real payments had been based on cash since the seventeenth century. Salary payments made in cash constituted 77 % of the government budget in 1630 and 62 % in 1670 (Barkan, 321–325). Delays in the payments led to uprisings initiated by the janissaries, and some of these uprisings occurred in the years following the skip period. In order to keep the income-expense balance, the government looked for

borrowing and devaluation. That meant a new tax and it affected the peasantry most. This chain of problems caused the peasants to leave their homes.

At the instigation of the head of the provincial treasury, Morean Osman Effendi, a new calendar known as the Financial Calendar, based on the Julian Calendar, was established in 1794, in order to solve the problem for the treasury arising from the day difference (Nevsâl-i Millî, 9). Because the name Julian was Greek, they tried to overcome the problem by using the Financial Calendar, also called the Julian Calendar, only in financial transactions after 1794 (Millî Nevsâl, 15–16). The starting date of this calendar, which was based upon the solar year and used in all official fields after 1840, was the Hijri of Muhammad (Ahmet Şakir, 25). The months' names were picked from ones used by the Assyrians and Romans (Gökdoğan, 91). Thus, an interesting calendar whose year digit was determined according to the lunar year, and whose month and day digit was determined in line with the solar year, was established. According to Ahmet Cevdet Pasha, whose studies drew attention to the subject of calendars, such a calendar had never been used by any other nation before 1582 (*Takvimü'l-edvâr*, 54–55). Meanwhile, Continental Europe preferred the Julian rather than the Gregorian Calendar which they had been using since 1582, and it was known as *Efrenci* by the Ottomans (Akgür, 1996, 71). Ottomans were familiar with this calendar from the Orthodox religion (*İkdam*, 18 Kanun-i sani 1332).

The move to start using the Financial Calendar for all official matters from 1840, which previously had been used only for financial transactions, was due to the centralization initiative of the Tanzimat Reform Era. Along with centralization, the number of troops, and through the developing bureaucracy, the number of officers was increased. An extraneous factor influenced bringing the subject of the calendar into question and from then on it never lost its importance. Because of the efforts of the Ottoman Empire, which gained speed after the Treaty of Balta Limanı, they signed a compact with the United Kingdom in 1838, for unification with the capitalist world.

Executives of the Tanzimat Reform Era, especially Ali Pasha, took action with a number of pragmatic arrangements to create the prerequisite conditions for a capitalist economy. Hence, they took the European calendar, which had reached a certain standardization after the French Revolution, in exactly the same way, and the Ottomans also adopted the length and weight measuring systems. Ahmet Cevdet Pasha wrote a work entitled *Takvimü'l-edvâr* at the request of government executives, when it was deemed necessary to investigate the problem of how the dates fell. In this work, Pasha drew attention to the fact that the year 1288, which had escaped the attention of the executives and had been forgotten, was the skip year (Ma'rûzât, 206–207; Tezâkir, 109–110). The government bonds due to be issued in 1288 would be invalidated and that would cause trouble for the government and the courts (Şakir Paşa, 25; Islâhü't-takvim, 27). Warnings, especially from Ahmet Cevdet Pasha and the commissions that were working on the same matter, were not taken into account. The tradition was abandoned, and the final solution considered was to remove the sıvış yılı (BOA, YEE.KP, 86-35/3454; Ma'rûzât, 208).

It took time to integrate the Financial Calendar into daily life. In fact, in birth certificate applications brought after the Tanzimat Reform Era, the birth dates of some people were given based upon the Hijri Calendar, while some used the Financial Calendar (BCA, 030.10, 124.886.11; Uluçay, 136). In the year when the Financial Calendar was put into practice, postal services were also made open to the public (Eskin, 16). After almost half a century, in 1901, a small adjustment was made to this calendar by the Ministry of Post and Telegrams. In Europe, the day difference between the Julian and Gregorian Calendars was being discussed (The Times, 21 Oct. 1901). Because of the Ministry of Post's decision, the 1-day shortness in the Financial Calendar was increased to 13 days, which made it 584 years behind and 12 days shorter than the Gregorian Calendar. For postal transactions, it was decided that the months would be indicated by the number that referred to which month of the year it was, but not by its name.

Alongside changing the traditional units of measurement and weight, Tanzimat dignitaries intended to accept a new calendar system just like the Jacobeans did in France, in order to make advances towards Europe (Kasaba, 20). However, not only were they unable to touch the calendar phenomenon reinforced by tradition and also the strong effect of religion associated with Hijri, but they were also going against the requests of congregations made in this direction.

Despite this, the Ottomans decided to use the same calendar which had been used in London, Paris, and Rome since 1910 and followed the congresses where the possibility of indicating time on a single scale was being discussed. The emphasis was placed on the positive effect of having only one calendar for the world economy, which would be used worldwide (The Times, 27 Oct. 1926). Wanting to act in unison with Europe, the Ottomans took action to regulate the calendar and the metric and hour system. They called this "putting the basis of amalgamation into practice" (Ergin, 264). The understanding of amalgamation would be taken in hand by the Financial Calendar (Nevsâl-i Millî, 9).

The Party of Union and Progress that steered government policies after the Second Constitutionalist Period did not have sufficient strength either to procure acceptance of the Hijri Calendar as the calendar for daily life, the Gregorian Calendar being the only calendar used in relations with Europe even unofficially, or to remove the Financial Calendar (Takvimü's-sinîn, XX) which was deemed necessary to abandon by the leading experts. The party sought reformation only, but on 22 September 1911, this was rejected by the Council of State, on the grounds that the attempt to accept it as the beginning of the year would lead to confusion (BOA, MV, 124/66).

The Financial Calendar was criticized, as its origin was the same as the one used by the Slavs who gained their independence following the Balkan Wars. Thus, the Financial Calendar, which was the one used by the enemies, was once again brought onto the agenda in the second year of the First World War. At that time, the Ottoman armies were fighting their enemies in Galicia, Macedonia, and Palestine, and communication and contact with the allies were gaining importance in order to avoid confusion. When using the main means of communication, telegrams, not only was it necessary to use the same language as the allies but also to indicate the same date they used. Meanwhile, the old enemy but the new ally, the Bulgarians, had accepted the calendar that was used by Western countries (*The Times*, 29 March 1916).

The government's intention was to make up the difference of the 13 days between the Financial and Gregorian Calendars. When the government asked for such a change, it also made clear that the birth of Christ would never be accepted as the beginning point of the calendar (*1332–1333*. . ., 358). When the matter was brought to the agenda of the parliament, Mr. Talat, Minister of the Interior and Treasury, who spoke on behalf of the government, reminded them that the Hijri Calendar had not been tampered with. He also said that the government's intention was to make up the difference of 13 days and to take the beginning of the year as January. He finished his speech by stating that the state treasury would make a profit of 180,000 liras after this change, and it would also make a loss at the same rate if the change was not brought about (MMZC, 11 Şubat 1331, 124–145). However, a few days later, the government, unable to obtain what it had asked for from the parliament, announced that it had revoked the law.

As well as the Hijri and Gregorian Calendars, all other calendars take their holy dates as the starting point. The Ottomans went further in that they considered the 1300s sacred. That is to say, when the government raised the question of the calendar once again, it was discussed in parliament whether the year digit would be indicated by the 1300s or 1900s. The problem was resolved with the notion that the 1300s belonged to the Nation of Islam (*Tasvir-i Efkâr*, 1 Mart 1333), and for this reason, the 1300s continued to remain on the calendar.

The discussions continued for a year, ending with a law that came into effect on 8 February 1332. The Financial Calendar was abolished and the Gregorian-based Western Calendar started to

be used (BOA, İ.DUİT, 87/22). By skipping 13 days, 1 March 1333 followed 15 February 1332. The year of 1333/1917 started from 1 March and lasted 10 months, with the next year, 1334/1918, starting as of 1 January (Takvimü's-sinîn, X; *Tasvir-i Efkâr*, 1 Mart 1333). With the new regulations, 2 months and 16 days were missing from the year 1917. In the period when the expenses were increasing during war time, the government budget gained much more importance. The issue of how the gap caused by the period skipped from the year 1917 could be filled was resolved thanks to certain guarantees given (BOA, MV, 205/141; DH. UMVM, 1/53). As such, the government guaranteed that there would be no problem with extracting taxes and rents and with the tax-farming contracts. Also, the regulations did not deeply affect people's daily lives although there were minor inconveniences in the official business of the citizens and the provincial administration had a little difficulty in adopting January as the beginning of the year.

The necessity of determining the equivalents of certain days in the new calendar was raised by a German diplomat's question on whether the sultan's ceremony of accession was changed or not (BOA, DH.İUM, E30/29; DH.UMVM, 124/101). In those days when the press also helped the community, several associations drew attention to their work. For instance, it was important that the Müdafaa-yı Milliye Cemiyeti had wall calendars prepared based on the Western Calendar. On these new wall calendars, sections indicating the religious dates were included. However, a few years later, as with the wall calendars, it was discovered that the dates indicated in pocket and desk calendars had not been determined correctly by the Office of the Chief Astronomer (Müneccimbaşılık). In the final days of the empire, it was discovered that the Office of the Chief Astronomer had not exercised the necessary controls and, more precisely, had neglected its duty (BOA, DH.İUM, 19-18/1-38).

The reaction against the Western Calendar broke out due to a combination of the Party of Union and Progress (İttihad ve Terakki Cemiyeti) and the resentment felt towards its leaders. At the beginning of the year 1920, the *Tasvir-i Efkâr* newspaper that had previously written on the issue of procuring society's acceptance of the new calendar now appeared before the society with a quite different discourse. The newspaper reportedly found the calendar change meaningless and strange, made by the Party of Union and Progress hurriedly during the war. The paper also regarded the acceptance of the New Year start date as the product of "wise-guy brains" (*Tasvir-i Efkâr*, 1 Kanun-i sani 1336).

In fact, the newspaper reflected the views of society, whose voice had not been heard until then. British and French hostility increased after the Armistice of Mudros, applying to almost anything that belonged to them, and also for the Gregorian New Year. Therefore, although the new year of the Hijri had not been celebrated in previous years, in the period of armistice, it started to be celebrated with nostalgia, with a religious emphasis added to it. In contrast, the Muharram, the first month of the year of Hijri, reminded the Muslims of the Karbala Incident, during which Hussain, the grandchild of Prophet Muhammad, was murdered (Akçura, 36). In the celebrations of the New Year of Hijri that took place at the end of the war, the longing felt for Islam, the period before the Party of Union and Progress, meant that this historical event was discounted. Thus, the high state officials appeared before the sultan and participated in the official New Year ceremony (*Tasvir-i Efkâr*, 27 Eylül 1335).

With the aim of modernization, the executives of the Turkish Republic, which was founded in 1923, were able to take the radical decision to deal with the Hijri Calendar. The developments occurring outside Turkey were also effective in supporting their cause. The League of Nations wanted to create a global calendar by making a calendar reform by means of commissions it had established (*The Times*, 27 Aug. 1923). As, in the Gregorian Calendar, the number of days in the months were not equal to the quarter and half periods of the year, but for the sake of convenience in commerce, industry, transportation, and communication, it was required to stabilize these periods (*The Times*, 27 Oct. 1926). The attempt of

the League of Nations remained inconclusive, but the Turkish executives, who followed the reform exercises closely, did not hesitate in accepting the Gregorian Calendar.

By enacting a law into practice, dated 26 December 1341/1925, the calendar problem that had persisted since the Ottoman period was resolved. The Calendar of Garbi was revoked by the law specified, and the Gregorian Calendar started to be used under the name "International Calendar" as of 1 January 1926. Usage of the Hijri Calendar was restricted, and its use was approved only when determining the sacred days and months (Üçer, 122). In justifying the decision of the law, it was written that the Western Calendar (Takvim-i Garbî), which did not have any scientific foundation, was erroneous and the sacred days would be determined based on the Gregorian Calendar, in accordance with the technical principles of the observatory (Öztürk, 106–107).

When the law was brought to the agenda of the Turkish Grand National Assembly, some members of the parliament were vocally opposed. However, compared with the strong opposition of the Ottoman Parliament and the members of notables, this group remained a minority. Such opposition seen in the parliament was barely apparent in the press, which supported the "Calendar Revolution" unconditionally. Thanks to this law, a step was taken towards westernization and the new Turkish Republic would proceed on its way by removing a calendar, which was a thing of the past. In the meantime, the Hijri Calendar, which had been identified with the Ottoman Empire, had its share of criticism (*Cumhuriyet*, 1 Kanun-i sani 1926).

The new calendar brought to Turkey the tradition of celebrating the New Year in the European style. New Year celebrations took place on the night between 1926 and 1927, attracting great attention, and the celebrations lasted all night long. Also for the first time, on that night the power administration started the tradition of turning off the city lights in Istanbul for a minute at exactly 12 o'clock (Tuna, 41–49).

The latest development on the matter of the calendar was the alteration of the names of the months. The process of changing the names of the months was initiated in the course of translating the Constitution of 1924 into Turkish in 1945. The names teşrin-i evvel/birinci teşrin, teşrin-i sani/ikinci teşrin, kanun-i evvel/birinci kanun, and kanun-i sani/ikinci kanun were replaced with Ekim (October), Kasım (November), Aralık (December), and Ocak (January), respectively.

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Caraka

Guy Mazars

Caraka is the editor of a treatise of Āyurveda which bears his name, the *Carakasaṃhitā* or "Caraka's Compendium", a work with which classical Indian medicine really begins. The *Carakasaṃhitā* is supposed to contain the teaching of the sage ► Ātreya Punarvasu, recorded by one of his disciples, Agniveśa, and revised by Caraka. Ātreya and Agniveśa belong to the realm of legend, but Caraka is likely to have been a historical figure. Indeed, according to the Chinese version of a Buddhist text, translated from Sanskrit in the fifth century AD, a physician of the same name was practising at the court of the Scythian king Kaniṣka. Several scholars place this king at the end of the first or second century AD. Like Aśoka (264–227 BCE) some centuries earlier, Kaniṣka was well disposed towards Buddhism and protected it. During his reign, Indian culture underwent a great expansion. The redaction of the *Carakasaṃhitā* thus goes back to this period, if it is indeed the same Caraka.

However, the text which has come down to us is a composite work. It contains more recent portions added at the time of its revision by an author from Kashmir, Dṛḍhabala, who probably lived in the fifth century AD. But the core of its content is much older since Caraka himself had only reconstructed an already existing work, cited under the name of *Agniveśatantra*, the "Book of Agniveśa". At least one of the redactors of the "Compendium" was familiar with the diets and habits of peoples from different parts of the world. The *Carakasaṃhitā* was commented upon before the ninth century by Jejjaṭa, who may have been a Kashmirian or an inhabitant of Sindh. Then, in the eleventh century, Cakrapāṇidatta wrote a commentary called *Āyurvedadīpikā*, which has been preserved and edited. Cakrapāṇidatta was a native of Bengal, himself the author of the *Cikitsāsaṃgraha*, a well-known manual of therapeutics. He wrote other works, including the *Dravyaguṇasaṃgraha*, a short treatise of materia medica. According to the Arab bibliographer Ibn an-Nadīm, in his *Kitāb al-Fihrist* (Index of Arabic books, completed in 988 AD), a Persian version of the *Carakasaṃhitā* had been translated into Arabic by the time of the first 'Abbāsid caliphs (eighth century).

In its present form the *Carakasaṃhitā* consists of 120 chapters which are divided into 8 parts (*sthāna*):

1. Thirty chapters in the *Sūtra* section dealing with various topics, including pharmacology, diet, some diseases and their treatments, physicians and quacks;
2. Eight chapters in the *Nidāna* section dealing with the causes of eight main diseases;
3. Eight chapters in the *Vimāna* section dealing with different topics such as "taste", logic, vessels, pathology and medical education;
4. Eight chapters in the *Śārīra* section dealing with embryology and anatomy, and on the connection between the body and the mind;
5. Twelve chapters in the *Indriya* section devoted to diagnosis and prognosis;
6. Thirty chapters in the *Cikitsā* section dealing with therapy;
7. Twelve chapters in the *Kalpa* section on pharmacy; and
8. Twelve chapters in the *Siddhi* section devoted to general therapy.

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Cashewnut Processing on the Malabar Coast

K. T. Rammohan

The cashewnut processing industry on the Malabar Coast grew around the port towns of Quilon, Calicut and Mangalore, which had cashew-growing hinterlands. Cashew was not a systematically cultivated tree crop. In earlier days, poor people gathered the nuts, roasted them in mud pans, removed the shells by hand and sold the kernels in nearby markets. From the early decades of the twentieth century, trading companies from the West operating on the coast began to purchase shelled kernels from local people for export. After sun drying, cashew kernels were packed in mango wood cases lined with newspaper and shipped out, mainly to Marseilles and occasionally to London from where these would be re-exported. From the 1930s, with the emergence of the United States as a major buyer, the industry gained substantial momentum. To meet the increased demand, the trading companies resorted to the putting out system of production. The companies bought raw nuts locally (and also imported nuts from East Africa) and distributed these to people, who pan-roasted and returned the shelled kernels to the company. The kernels were dried, peeled, graded and packed at the company premises. Later, as the putting out system gave way to direct production by firms, factories where all the operations were undertaken emerged. The factories employed women and children of lower castes and outcastes who were paid very low wages. Over 90 % of the workers were women. Men, again drawn from lower and depressed castes, were engaged primarily in roasting.

Cashewnut processing involved five principal operations: roasting, shelling, peeling, grading and packing. In the early factories roasting of nuts was done in the open air in iron pans. From 1932, iron pan roasting was replaced by drum roasting. Under the new method, an open-ended drum (rotary cylinder) was placed over a fire in a tilted position. Raw nuts were fed from one end, and roasted nuts were collected from the other. Each cylinder needed six persons to operate: the first person attended to the furnace, the second and third fed the raw nuts, the fourth rotated the cylinder, the fifth removed the roasted nuts, and the sixth sprayed water on the roasted nuts. The workers wrapped themselves in gunny bags to protect themselves from burns. By the mid-1930s, hot oil roasting replaced drum roasting. Here, raw nuts were roasted in a bath of cashew shell oil maintained at about 200 °C. Due to the high temperature, the oil cells of the nuts broke, releasing their contents; and the nuts were then roasted to the desired degree. Cashewnut processing yields a by-product – cashewnut shell oil that has industrial and strategic uses. This could be extracted in full only in oil-bath plants. All these methods used cashewnut shells as fuel.

After roasting the nuts were shelled. This was the most arduous operation and had to be done in an uncomfortable squatting posture. Nuts were placed on a flat stone and were gently hammered with the help of small wooden mallets, to remove the shells. A high degree of skill was required to ensure that the kernels did not break. Peeling the skin off kernels was also a dexterous, repetitive and loathsome task. The kernels were then graded and packed.

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Cave Architecture of India

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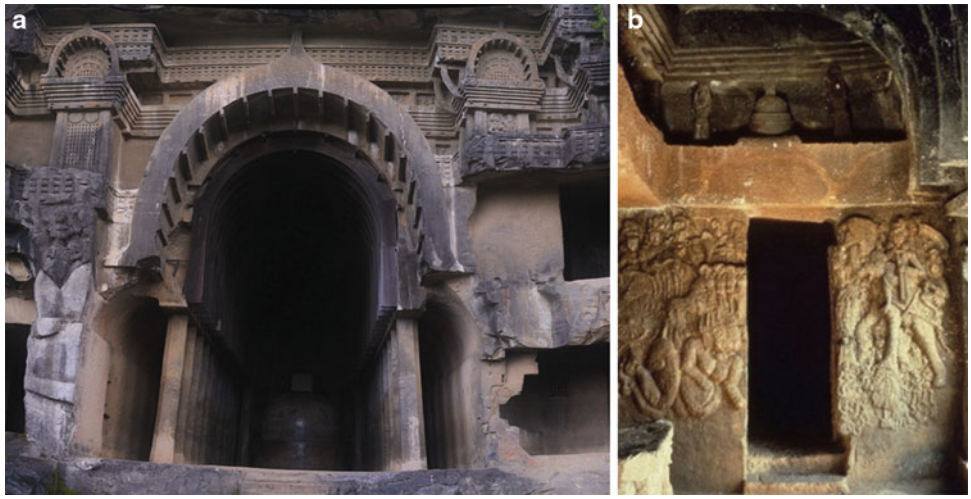
Caves in ancient India were places of special relevance. Aside from offering natural shelter, they were regarded as *loci* of supernatural powers and spiritual enhancement. Located at the *nexi* of sacred geographies and often associated with local deities, caves were favored abodes by hermits and renouncers. Elaborate rock-cut architectural structures were created for ascetics to use during the Maurya period (322–185 BCE) with King Ashoka (304–232 BCE) being the first to endow man-made caves to the Ajivika ascetics at Barabar Hill (Falk 2006). The four Barabar caves located in a rocky outcrop in the Gaya district of Bihar preserve distinctive plans with rectangular spaces attached to a circular, hut-shaped room at one end. The cave interiors are plain and flawlessly polished in a manner that alters light and sound. The only decoration appears at the entrance of the so-called Lomas Rishi cave where a portal motif with an architrave embellished by elephants and *stupas* is engraved in the living rock (Fig. 1).

During the second and first centuries BCE, rock-cut structures for ascetics were also created in Orissa in the Udayagiri and Khandagiri hills (Mitra 1975). These caves consist of simple series of cells with decorations above the entrances representing trees, elephants, and figures reminiscent of types seen in Shunga terracotta plaques. The Hathigumpha cave at Udayagiri carries a famous inscription by the local king Kharavela. From this time onwards, simple rock-cut complexes also began to develop in Gujarat, in a prosperous area involved in long-distance trade where both Jain and Buddhist religions thrived. The early caves at Junagadh, among others, include simple cells opening on porches with minimal ornamentation that takes the form of auspicious emblems (Soundara Rajan 1985).

Between the second century BCE and the second century CE, a surge in Buddhist patronage led to the establishment of many Buddhist rock-cut sites in Maharashtra along the western edge of the Deccan Plateau (Dehejia1972; Dhavalikar 1984). These excavations were large and elaborate and typically included monastic residential caves along with an apsidal hall destined for worship (Burgess and Fergusson 1988). Called *chaitya-griha* or *chaitya* hall in the votive inscriptions, this sacred space presents a row of columns running parallel to the walls and a rock-cut stupa placed at its end. The caves at Bhaja were among the earliest in western Deccan (second to first c. BCE): the *chaitya* hall was finished with wooden elements such as beams inserted in the rock vault and a wooden façade now missing, and rock-cut images of arches and balustrades with *mithunas* or couples frame the entrance. The monastic residences at Bhaja consist of series of cells equipped with stone beds;

Cave Architecture of India, Fig. 1 (**a**) Lomas Rishi cave, general view and (**b**) entrance to the cave (By Harry Falk)

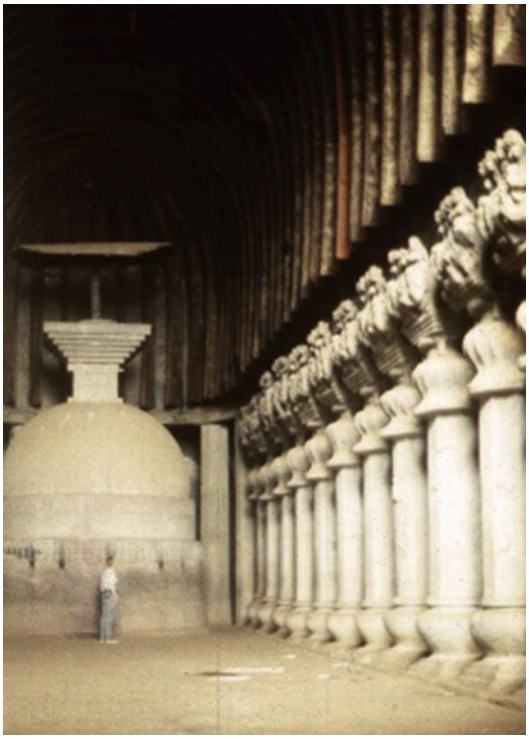


Cave Architecture of India, Fig. 2 (**a**) Bhaja, *chaitya* hall, and (**b**) cave 18

they open on small rectangular porches, generally undecorated, with the exception of cave 19 where carved in low relief are royal figures riding an elephant and a horse-pulled chariot, previously identified as the Vedic gods Indra and Surya (DeCarolis 2000). Buddha images do not appear in the early caves of western Deccan (second c. BCE–second c. CE) generally associated with the Hinayana tradition, and the figural decorations in this phase consist mostly of images of *mithuna* or couples such as those at Bhaja or guardian *yakhshas* like those at Pitalkhora (Figs. 2, 3, and 4) (Deshpande 1959).

Buddhist cave architecture in western Deccan soon emancipated itself from the use of wood, and most *chaitya* halls came to be entirely carved out of living rock. The *chaitya* hall at Karle has an ornate stone façade and an interior with elaborate pillar bases and capitals, while the Ajanta *chaitya* hall no. 10 was embellished by vivid paintings (Schlingloff 1987). Sometime during the first century CE, well-planned monasteries, with rock-cut cells aligned along three sides of a square court, were introduced in Buddhist cave architecture; caves 3 and 10 at Nasik bearing inscriptions of the Kshatrapa king Nahapana and

Cave Architecture of India, Fig. 3 Pitalkhora, Yaksha

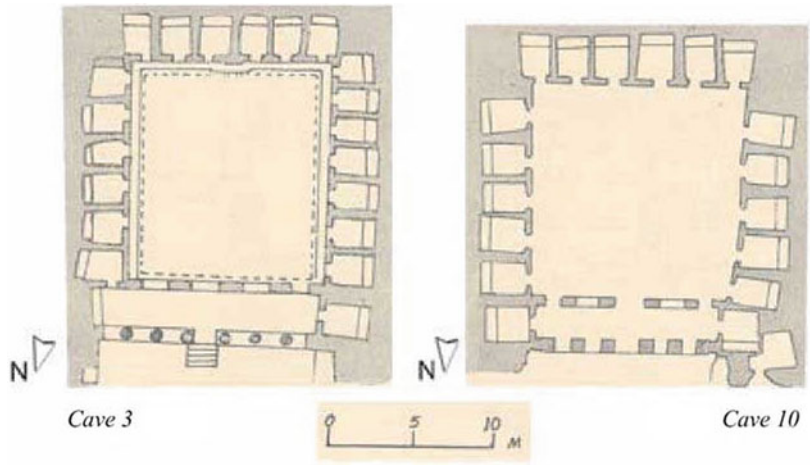


Cave Architecture of India, Fig. 4 Karle, *chaitya* hall

the Satavahana rulers constitute excellent examples of such square *vihara* cave types (Fig. 5) (Bhandare 2006; Rees 2009).

Buddhist rock-cut monasteries in western Deccan were often supported by gifts of traders and craftsmen, as suggested by in situ votive inscriptions (Burgess and Indraji 1976), and the sites benefited from the wealth brought to the area by thriving Indian Ocean trade (Ray 1981). The caves, called *lena* in the inscriptions, grew in clusters around important passes along the edges of the plateau (Sahyadri Range), near trading routes (Chakraborti 2005; Lahiri 1992), not too far from urban centers, and often in areas where agricultural land was readily available (Brancaccio 2010). The Buddhist caves at Bhaja, Karle, and Bedsa were grouped along the Bor Ghat pass; the large four clusters of caves at Junnar (Tuljalena, Manmodi, Shivneri, and Lenyadri) overlooking fertile land were also situated in proximity of the Nanaghat pass. The caves at Pitalkhora, Ajanta, and Aurangabad were strategically located along major internal trade routes, while in coastal Konkan flourished the Kondivte, Kuda, and Kanheri caves. The latter, located near the ancient port of Kalyan, experienced an unusually long period of activity (Ghokale 1991; Ray 1994). Stylistically related to the earliest Buddhist sites in western Deccan are also the caves at Guntupalli in Andhra Pradesh (ca. second c. BCE) that include a round *chaitya* hall similar to the one from Kondivte in Maharashtra (Brancaccio 2013).

The fifth century marked a renewed interest in patronage of rock-cut architecture in northwestern India. Most relevant are the Vaishnava caves at Udayagiri in Madhya Pradesh realized under the Gupta dynasty (Willis 2009) and the major

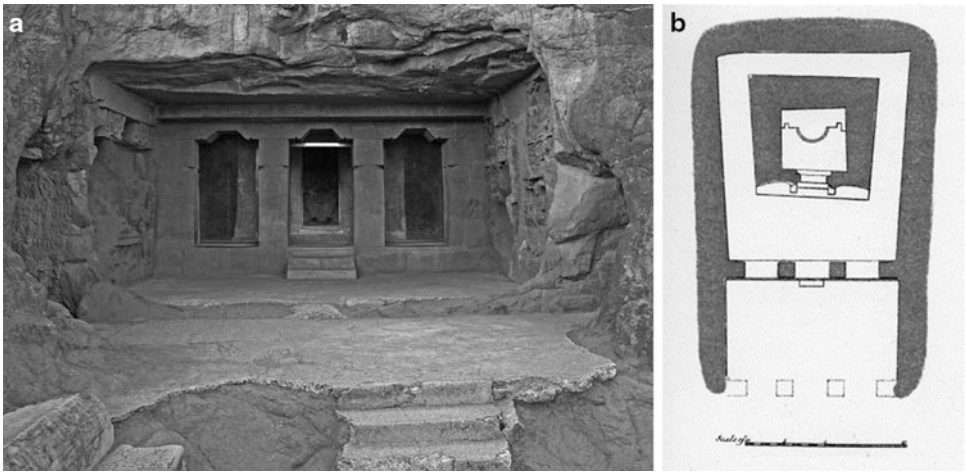


Cave Architecture of India, Fig. 5 Nasik, caves 3 and 10, plans after Gethin Rees, http://www.ancient-asia-journal.com/article/view/aa.10209/47

Cave Architecture of India, Fig. 6 (**a**) Ajanta, *chaitya* hall 26, and (**b**) cave lower 6 (By Nicholas Morrissey)

expansion of the Buddhist caves at Ajanta undertaken by the Vakataka king Harishena and his entourage (Spink 2007-14). At Ajanta two more *chaitya* halls and 20 additional *viharas* (monasteries) were created at the end of the fifth century, and they were all embellished by elaborate paintings of *jatakas*, *avadanas*, and other Buddhist images that survive only in part (Schlingloff 1988; Jamkhedkar 2009; http://www.ajantastudygroup.com/). By this time the Buddha image had become the focus of worship at Ajanta: aside from sculptures on *chaitya* halls stupas, each *vihara* at the site included a cell with a larger than life sculpture of the Buddha seated on a throne placed on axis with the entrance (Schopen 1997). Buddhist patronage continued well into the sixth century at the nearby site of Aurangabad where new architectural layouts were developed. Smaller caves were created, with or without side cells, that included a square central shrine with a Buddha image surrounded by a corridor for circumambulation as in caves no. 2, 5, 7, and 8 (Figs. 6 and 7) (Brancaccio 2010).

Buddhist caves in western Deccan experienced a slow decline beginning in the sixth



Cave Architecture of India, Fig. 7 (**a**) Aurangabad cave 2, view and (**b**) plan

Cave Architecture of India, Fig. 8 Sadashiva at Elephanta

Cave Architecture of India, Fig. 9 Ellora, cave 29, Dhumarlena

century, as patronage in the region shifted to the creation of Shaiva rock-cut temples (Tarr 1969; Soundara Rajan 1981) – most notably the ones at Elephanta in Konkan and at Ellora in the Aurangabad district. The unfinished great cave or cave 1 on the Elephanta Island took rock-cut architecture to monumental proportions with its huge, rectangular hall including colossal pillars, multiple points of access, as well as *linga* shrines (Spink 1982; Michell 2002; Dhavalikar 2005). Elephanta cave 1 is best known for the monumental relief of a three-headed Shiva (usually labeled as Sadashiva) dominating the south wall (Fig. 8) and for the large tableaux depicting other forms and feats of the god carved on the remaining rock walls (Collins 1988). It is also during the early sixth century that a first group of caves dedicated to the god Shiva was established at Ellora (http://elloracaves.org/). These excavations are stylistically linked to the

Elephanta cave as exemplified by cave 29 also known as Dhumar Lena (Spink 1967). It is not until the eight century, after more Buddhist caves had been cut on the southernmost edge of the Ellora cliff (caves 2–12) (Malandra 1993), that the spectacular rock-cut Kailash temple (cave 16) was created under the Rashtrakuta king Krishna I (Dhavalikar 2005). This rock-cut structure is covered by elaborate carvings and echoes the shape of Shiva's mountainous abode (Brancaccio 2013); it stands completely free from the rock cliff, where multistoried pillared halls and rectangular chapels are excavated all around. In the ninth century Ellora was also occupied by the Jains who cut a few more elaborate caves (caves 30–34) on the northern edge end of the site (Figs. 9 and 10) (Owen 2012).

Cave Architecture of India, Fig. 10 Ellora, cave 17, Kailash temple (By Lisa Owen)

The Deccan was the heartland of cave architecture, and the Chalukya kings continued the tradition of rock-cut temples at Badami and Aihole in Karnataka, where caves were cut between the end of the sixth and the eight century (Srinivasan 1964). The four Badami caves, three Hindu and one Jain (no. 4), have simple layouts that include a shrine, a rectangular pillared hall embellished with sculptures, and a porch or *mandapa*. They seem to be stylistically related to the earliest Hindu caves at Ellora; in particular, Badami cave 3 dated by an inscription to 578 is akin to cave 21 at Ellora (also called Rameshvara (Tarr 1970)) (Fig. 11). The small Ravana Phadi cave dedicated to Shiva at Aihole seems to bridge, in terms of style and design, the

Cave Architecture of India, Fig. 11 Badami, cave 3, porch

Cave Architecture of India,
Fig. 12 Mahabalipuram, Arjuna, and Draupadi Rathas

rock-cut tradition of the Deccan with that of Tamil Nadu.

Under the Pallava dynasty cave architecture blossomed in Tamil Nadu, along the southeast coast of India. The most impressive are the Hindu caves and monolithic rock-cut temples at Mahabalipuram dating to the seventh century CE (Nagaswami 2011). The caves are many and modest in size; they generally include a shrine that opens directly onto a small porch embellished by sculptures of Hindu gods. The most remarkable are the so-called Varaha, Trimurti, and Mahishasuramardini caves. Among the nine freestanding monolithic temples, five are clustered together and are known today as the five Rathas. These unfinished monuments replicate different building types in the living rock, and the four that appear to be aligned (the so-called Draupadi, Arjuna, Bhima, and Dharmaraja) were originally carved out of a single boulder. Each temple, dedicated to a different Hindu god, is intricately carved on the outside and is associated with a sculpted *vahana* or divine animal; the interiors are barely roughed out or simply unfinished (Fig. 12) (Dehejia and Davis 2010).

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Celestial Vault and Sphere

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The celestial vault is the apparent surface of the sky – both the night sky against which the stars appear to be placed and the blue expanse of the daytime sky. This surface may be assumed to be either imaginary or real and in the latter case is commonly referred to as the *firmament*.

The idea that the celestial vault, and particularly the daytime sky, is a physical cover of some kind is found in the cosmologies and myths of many cultures. In sub-Saharan Africa, a widespread belief is that the daytime sky is a solid blue vault resting on the earth, on which the sun moves. During the night, the sun is thought to return to the east by passing either under the earth (e.g., the Luyia of Kenya) or behind the solid sky (e.g., the Zulus of South Africa); in the latter case, it also produces the stars by shining through small holes in the vault. The idea that the sky is a solid surface was also commonly accepted in China, India, among American Indians, and Australian aborigines. Ethnic groups in northern Eurasia thought of the sky as a roof to protect the earth and life and often described it as resting on a central pillar. In the hero tales of the Yakuts, the sky was said to be hemispherical, resting on the outer edge of the world. In the mythologies of Finland, Lapland, and neighboring regions, the celestial pole or the pole star was described as the "nail of the sky" which supports the celestial vault and around which it revolves. The Lapps, Finns, Yakuts, Japanese, and Hebrews sometimes described the sky more specifically as a tent roof. The most popular conception of the sky in ancient Egypt was that of a blue-water surface, a continuation of the sea or the Nile. Similar ideas were applied to the night sky. The Milky Way appeared to some as a stitched seam, and the stars as tiny holes in the fabric of the celestial vault.

The large amount of attention given to the nature of the celestial vault in cultures all over the world seems to stem mainly from its perceived function as a substratum on which the celestial bodies are situated or upon which they move. The celestial bodies and their movements, and to a lesser extent the celestial vault itself, were of absorbing interest to people in all cultures for a variety of reasons, both practical (e.g., as a basis for the calendar and agricultural practices), magical (e.g., predicting future events), social (regulating social events), and religious (e.g., believing the celestial vault, or the space behind it, to be the home of the gods). Among many native tribes in Colombia, for example, "the sky is seen as an enormous blueprint of everything that did, does, or will happen on the earth; a map replete with information on every aspect of biological and cultural behaviour" (Reichel-Dolmatoff, 1982, p. 165). This information is thought to have provided the people with a measure of security. Furthermore, the diurnal cycle of the celestial vault, coupled with the regular appearance and disappearance of the sun and stars, may have instilled by similarity belief in rebirth and the transcendence of death (Belmonte, 2010).

Although the perceived solidity of the celestial vault implied a fixed form for the sky, that form was seldom clearly defined. There was some debate among early astronomers in China on whether the celestial vault might be strongly flattened, perhaps even a plane parallel to the earth's surface. For example, the astronomical chapters of the official history of the Chin dynasty (265–420 AD), written in the seventh century under the supervision of Emperor T'ai Tsung, contain a discussion by the scholar Ge Hong (previously spelled Ko Hung [283–343]) of the theory that the sun cannot be seen at night because it moves a great distance away from the earth. Ge Hong argued (Ho, 1966, p. 57): "If it is said that the sun can no longer be seen because it has gone a very great distance from us, then when the sun sets, on its way towards the north, its size should diminish. But, on the contrary, the sun becomes larger at sunset." This refutation of the flattened vault theory did not originate in China. It was stated in similar words by the Greek astronomer Claudius Ptolemy in the *Almagest* (Book 1, chapter 3), written around 142 AD. The similarity of the wording leaves little doubt that intellectual contacts existed between China and the Middle East at the time.

The idea that the celestial vault is actually flattened has been ascribed to Empedocles, a Greek philosopher of the fifth century BC. Ptolemy's refutation of the theory was later transmitted to Islamic scholars as part of the *Almagest* and was slightly elaborated by the astronomer al-Farghānī in the ninth century. However, by this time, most astronomers had accepted that the celestial vault represents the upper half of an imaginary (or sometimes real) spherical surface (or a set of concentric surfaces), called the celestial sphere, which carries the stars. The other half of this sphere is below the horizon. Celestial spheres were key elements in the cosmological models of Aristotle, Plato, Ptolemy, Copernicus, and others. These authors saw the stars and planets as being embedded in rotating, concentric, transparent spheres. Others regarded all the celestial bodies as moving on the same sphere, with the exception of meteors. Arab philosophers regarded meteors as occurring in the terrestrial environment rather than on the celestial sphere.

Irrespective of the assumed shape of the celestial vault, the apparent positions, sizes, and movements of the sun, moon, planets, comets, and stars have often been described as if these bodies are situated on a real surface. Estimates of the sizes and separations between the celestial bodies were therefore expressed as lengths or distances on the celestial vault rather than in terms of angles. For example, Chinese observations of comets from the second century BC to the nineteenth century were expressed in terms of the *zhi*, a length standardized as 311 mm in the ninth century. The zhi appears to have corresponded to an angle of a little less than 1°. Similarly, the Babylonian *ammat* (about 524 mm) represented either 2° or 2.5° at different times. And the Islamic fitr and shibr (spans later standardized as 152 and 178 mm, respectively) were equivalent to about 0.6° and 0.8°, respectively, in the astronomical work of Ibn Yūnūs during the eleventh century.

These lengths and angles seem to imply that the astronomers in each of the three cultures assumed that the celestial sphere had a radius of only some tens of meters. Numerous estimates of the perceived sizes of the sun and moon (usually seen as some 200–300 mm across) from classical to modern times in Europe support the same conclusion: there exists a universal tendency to describe perceived sizes and distances on the celestial vault as if the height of the sky is only a few tens of meters.

Although astronomers had long rejected the idea that the celestial bodies move along flattened trajectories, the Islamic physicist Ibn al-Haytham pointed out in the eleventh century that the sky usually *appears* flattened. He explained this as an illusion created by our perception of distant objects toward the horizon and the lack of such indicators of distance toward the sky. He furthermore used the flattened appearance of the celestial vault to explain the illusion that the sun and moon are enlarged near the horizon – an explanation that was transmitted to Western Europe during the thirteenth century and survived well into the twentieth century. Its importance lies in the fact that, for the first time, the perceived flattening of the celestial vault and the perceived enlargement of the horizon sun and moon were described as perceptual illusions (now studied by psychologists) rather than measurable phenomena to be studied by astronomers.

See Also

- ► Al-Farghānī
- ► Almagest: Its Reception and Transmission in the Islamic World
- ► Astronomy
- ► Ibn Al-Haytham (Alhazen)
- ► Ibn Yūnus

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Ceramics in Africa

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Pottery making is a very ancient craft in Africa, as some of the oldest pottery remains known in the world were discovered on this continent. Dating from around 10,000 BCE – i.e., one or two millennia after the inception of the Jomon pottery in Japan – they were excavated in the Aïr Region of Niger (West Africa) (Haour, 2003).

Throughout history, the craft has endured important changes in relation to the shape, function, and decoration of the products, as well as manufacturing techniques, scale of production, or the social status of the potters. The last decades have proved particularly significant in that

regard, due to the massive introduction of plastic and metal containers, social and economic transformations, the development of tourism and urban lifestyle, and the spatial extension of social networks. In most places, ancient pottery functions such as cooking, handling, and serving have been abandoned, while new categories of products such as decorative or commemorative items, flowerpots, tiles, braziers, or incense burners have boomed. Water jars, however, continue to be massively produced in some parts of the continent, as they provide the cheaper and most efficient way of keeping cool water in rural areas.

Social Background

A comparison of several hundred ethnographic sources (Information examined in this article comes from two bodies of data. Since 1990, members of the *Ceramic & Society Project* developed at the University of Brussels and its research associates have conducted fieldwork in Senegal, Gambia, Mali, Niger, Burkina Faso, Togo, Benin, Nigeria, Cameroon, Chad, and D.R. Congo, collecting information about some 1,000 potters in nearly 100 linguistic groups. The second body of data comes from a systematic perusal of the ethnographic and ethnoarchaeological literature devoted to pottery making in sub-Saharan Africa. These sources are of varying relevance and accuracy as they range from large-scale and detailed studies to more local/regional observations, or mentions in ethnographic monographs, administrative reports, and religious publications. Altogether, more than 900 sources have been processed, which relate to some 650 linguistic groups.) indicates that at last four–fifths of the African potters working today are women, which confirms the usual description of pottery making in Africa as a "female activity." But male potters are also encountered in several regions of the continent, where they either specialize in the making of particular vessels (big water jars, elite ware, bottles) while women produce the largest part of the repertoire, or produce the whole range of vessels in contexts where women are excluded from the craft, or work together with female relatives, carrying out specific operations such as clay extraction and transport, clay preparation, firing, and, above all, plastic decoration (Schildkrout & Keim, 1990).

The scale of production is highly variable, ranging from part-time, isolated artisans, whose products are essentially consumed locally, to full-time specialists working in workshops, whose vessels are distributed by middlemen in a 100–200 km radius. If men tend to be more frequently associated with the latter category, female potters may also be involved in mass production, especially in West Africa.

In many instances, pottery making is open to anyone. All one has to find is someone who is willing to serve as a teacher. This means, in practice, having a close relative, friend, or neighbor who engages in pottery making and does not mind spending time with someone who may subsequently become a competitor. But restrictions are also observed throughout the continent, which pertain to age, gender, geographical origin, and, above all, socio-professional affiliation. For example, in many Sahelian societies, potters belong to caste-like subgroups such as blacksmiths, bards, tanners, weavers, woodcarvers, hunters, or jewelers (Drost, 1968; Frank, 1998; Gallay et al., 1998; Gosselain, 2001; Haaland, 1978; Lyons & Freeman, 2009; Sterner & David, 1991, 2003; Tamari, 1997). The members of these endogamous specialist groups are associated with specific activities and duties and distinguished from the remaining population. They are regarded with a mix of awe and contempt by nonspecialists, who often consider them dirty and impure and fear being harmed by their power. Due to recent economic changes, however, caste-like structures may become permeable to other social groups in specific places.

Manufacturing Process

There are seven main stages in the pottery manufacturing process: (1) clay extraction, (2) clay processing, (3) shaping, (4) decoration, (5) drying, (6) firing, and (7) postfiring. While

most of these stages are mandatory, some – such as decoration and postfiring – are optional, although widely recorded across the continent (previous surveys of pottery manufacturing processes in Africa include Devisse, 1984; Drost, 1967; Gosselain, 2002; Krause, 1997; Livingstone–Smith, 2007).

Clay Extraction

Available data indicate that most African potters collect their clay within a 3–km radius from the place where they live and/or practice the craft (see Gosselain, 2002, pp. 40–41). Those who exploit sources beyond this threshold generally use animals, cars, trucks, or canoes to carry the clay. They also tend to make stocks that last from several weeks to the whole potting season.

Four categories of extracting techniques are observed in Africa: surface collection, pit extraction, underground gallery, and underwater extraction.

In surface collection, clay is extracted on or just below the surface, either on the ground (plain, fields, dried ponds, or riverbeds), a hill, or the wall of a slope or an embankment. After having eliminated the superficial organic and mineral layer, the potter extracts clay without really digging underground. The operation may be described as "peeling" a clay bed.

In pit extraction, potters dig vertically or diagonally into the ground, until an appropriate layer is reached. Most pits are some 1 or 2 m deep and 2 or 3 m in diameter. Due to repeated and intensive exploitation, they may take the form of a quarry, as in southeastern Nigeria (Nicklin, 1979, p. 349). Variations are observed in the way potters exploit and manage these structures. For instance, some use a pit until the clay layer is completely exhausted, while others abandon it when a specific depth is reached or as soon as it shows risks of collapsing.

Raw materials may also be extracted from galleries. This type of structure generally starts with the excavation of a vertical shaft. When the access shaft reaches the clay bed, the structure is extended horizontally (Livingstone Smith, 2007; Nwafor, 1980; Schneider, 1993). Galleries, like pits, are generally abandoned at the end of the potting season, but some may be used several years in a row, the access shaft being re-excavated each year.

Finally, a rather uncommon technique consists in extracting clay from the bed of an active river, as among Tikar of Cameroon and Punu of Gabon (Gosselain, 2002, pp. 52–53). Here, artisans build two small dams in the river, bail out the water contained between the dams, and extract clay before the upstream dam gives way.

It is usually in the course of other activities, and especially activities which force them to dig into the ground (e.g., tending fields, building houses, digging wells) or to frequent places such as riverbeds or swamps, that potters, members of their family, or any of their acquaintances may discover a new source and get the process leading to its possible exploitation under way. This involves assessing both the intrinsic qualities of the material (which often includes firing test vessels) and the compatibility of the site with other imperatives.

A first requirement is that the clay must have the right physical properties, i.e., its plasticity, texture, color, and even taste and odor must fit with a potter's personal requirements (see also Barbour, 1989; Brown, 1989; Frank, 1998; Trowell, 1941, p. 61; Woods, 1984, p. 305). If newly discovered clay is judged suitable, a second requirement is that it must be located nearby the potter's main occupational areas and/or working place. Since pottery making is often subordinated to other activities – such as farming and domestic tasks – potters tend to restrict their investment in time and energy or, at least, avoid scheduling conflicts when practicing the craft. Sources located nearby living or working sites, fields, rivers frequented for fishing, roads, or tracks are therefore more likely than others to be selected and subjected to long-term exploitation. In fact, about 90 % of the hundreds of sources that we visited in sub-Saharan Africa were situated nearby or within sites used primarily for other activities. Such a situation has an obvious impact on clay exploitation strategies. More importantly, it shows that clay extraction sites are not distributed randomly or according to

a craft-specific logic but are fully integrated in the territory frequented by both potters and non-potters.

Finally, rituals and taboos often surround the selection and exploitation of clay sources (Barley, 1994; Berns, 1993; Drost, 1964; Gosselain, 1999; Herbert, 1993; Pinçon, 1993). For instance, certain persons are systematically kept aside from extraction sites or places where clay is stored and processed: men when the craft is in the hands of women, women in opposite situations, uninitiated people, members of distinct social groups from the potters, little girls or boys, pregnant women, menstruating women, twins, warriors, etc. Likewise, artisans must avoid doing particular things on the eve of extraction or when engaging in clay collection: having sexual intercourse, talking, singing, swearing, urinating, manipulating certain objects, eating particular food, etc. Rituals and sacrifices (e.g., prayers, food offerings) may also be performed at the extraction site.

Clay Processing

As in most places around the world, African potters never use clays in their raw state. Processing operations may be grouped into four main categories: pretreatment, removal of nonplastics, addition of nonplastics, and homogenization.

Pretreatments usually consist in leaving the raw materials to dry, soak, or sour for hours, days, weeks, or even months. Soaking is usually done in a pit, an old jar, or a plastic container and used when clay is extracted in a dry state. It aims at allowing the material to regain its plasticity. If clay is already wet, the aim may be to obtain a better workability through increasing the amount and distribution of water between particles and pores. A long soaking time may also help in increasing plasticity through pH alteration and the subsequent flocculation of clay particles, but such souring process is quite rare among African potters.

When clay is sufficiently dry or wet, undesirable nonplastics may be removed through a series of techniques. The most common one is hand sorting, as potters usually remove coarse impurities such as pebbles, roots, or leaves when manipulating clay. But there are several other ways of controlling clay composition and texture. For example, potters may pound the clay on a stone or in a wooden mortar or grind it with lower and upper grinding stones. Finally, nonplastics may be removed by sieving with baskets, pierced calabashes, or imported nylon meshes. Potters may also remove the coarser fraction of nonplastics by shaking the crushed raw materials in a calabash or by winnowing it with a winnowing basket or a calabash. A last technique, levigation, is quite rare in Africa. Here, the material is mixed with water until reaching a colloidal state. After having removed the larger, heavier particles on the bottom of the container, water is left to evaporate and the finer fraction is retrieved (David, 1983; Gallay & Sauvain–Dugerdil, 1981).

Generally called "tempering," the addition of plastic or nonplastic elements to the clay matrix involves a large variety of materials: other clays, dust, mud, termite heap clay, sand, gravel, rocks (calcareous rocks, gneiss, schist, and asbestos), iron stone, grog (crushed, grounded, and/or sieved potsherds; Fig. 1 – by far the most common material), fired earth, ash, straw, cereal husks, grass, stems, bark, dung (horse, cow, goat, or donkey), shells, calcareous solution (grounded and sieved calcareous rock mixed with a large amount of water; Sall, 2005), or bark decoction.

The last processing step usually consists in a thorough homogenization of the material. Such operation is mandatory in clay processing and has a determinant impact on clay workability. It may be done in different ways: kneading with the hands, trampling with the foot, or pounding with various kinds of tools and supports (the most common ones are mortars and pestles, lower and upper grinding stones, and handles of diverse farming tools). Due to the frequent combinations of the four categories of treatments, as well as the diversity of tools, gestures, and materials involved, there exist hundreds of technical variants across the African continent. Such diversity sometimes leads processing techniques to become cultural markers at local or regional

Ceramics in Africa, Fig. 1 Pounding sherds in wooden mortars for obtaining grog, the most common temper in Africa. Note the use of tools and postures identical to those used in food processing

scales (Corniquet, 2011; Gosselain, 2008; Livingstone Smith, 2000).

Potters often explain that they act the way they do because of tradition (i.e., because of the way they have been trained), but also because using other processing recipes would lead vessels to break during drying, firing, or utilization. Such a conception may justify the use of different processing techniques in relation to the intended function of vessels or vessel parts. Among Koma-Gimbe of Cameroon, for example, potters simply pound the clay when making small vessels but add sand when making large beer brewing jars. They explain that jars would crack when drying if they did not do so (Livingstone Smith, 2000). Others examples of the use of different processing recipes for different uses have also been collected in other areas (Gallay & Sauvain–Dugerdil, 1981; Herbich & Dietler, 1991; Nicholson, 1929; Tobert, 1984; Trowell, 1941). Most commonly, however, potters use a single processing technique, irrespectively of the intended function of the vessels.

Another factor that explains the use of specific processing techniques is the relationship with techniques used in other realms of activity, such as food processing and agriculture. For instance, staple foods and clay may be prepared with similar tools and gestures and according to similar recipes. In the Bariba village of Tourou (Benin), for example, potters pound the clay in a wooden mortar and separate the fine and coarse fraction by shaking the material in a calabash. Then, they pound the coarse fraction a second time, and let it soak in a jar placed in the sun. When the liquid is sufficiently thick, it is sieved through a pierced tin can and mixed with the fine fraction of the raw material. Potters explain that this mixture acts as cement and that the best millet porridge is obtained in a similar way. Similarly, the clay desalinization technique observed among certain Jola Kasa potters of Casamance echoes agricultural practices in mangrove zones (Sall, 2005).

Symbolic or religious concerns may also influence clay-processing strategies (see examples in Gosselain, 1999). For instance, some Boko potters of Benin take great care in extracting all rootlets from the raw material. This is because rootlets are used to prepare a medication that prevents potters from "swelling" when fashioning vessels. Some West African potters often recycle archaeological sherds into grog, as they consider this material to possess particular qualities because "ancestors knew how to make stronger pots" or because "what has lain underground is stronger than what lies on the ground" (Livingstone Smith, 2007). Another example comes from Tukulor potters of Senegal who stop adding dung to the clay when they settle in Soninke communities, where dung is considered impure (Gelbert, 2001).

Ceramics in Africa, Fig. 2 Shaping a vessel with the diverging pounding technique, on a concave wooden anvil with a clay tamper (Photo by Olivier Gosselain)

Shaping

In most instances, the shaping process must be separated into two specific operations, according both to their purpose and the set of tools and gestures involved: (1) roughing out and (2) preforming. During roughing out, potters transform a lump of clay and/or joint pieces of clay together in order to constitute a hollow volume – the rough shape – whose form, often cylindrical, is not that of the finished product. During preforming, potters give the hollow volume its final geometric characteristics through scraping and smoothing operations.

Wheel throwing – not considered here – is only documented in North Africa, where male potters have used it for centuries. South of the Sahara, only passing references are made to the use of wheel throwing by a few male potters in the Lower Congo area. The Portuguese could have introduced the technique in the late seventeenth century (Vincentelli, 2003, p. 44), yet due to a lack of ethnographical information, it is impossible to know whether it is still used as such by Kongo potters.

Roughing Out

Techniques used in sub-Saharan Africa belong to seven main categories: (1) pounding in a concave form, (2) drawing of a ring-shaped lump, (3) superimposing and drawing of large rings, (4) molding (on concave or convex molds), (5) pinching, (6) drawing of a lump, and (7) coiling. As the last three techniques are widely documented outside Africa, only the first three will be considered here.

The pounding technique – also called "tamper and concave anvil technique" – consists in placing a lump or a pancake of clay on a mat-covered depression or a concave anvil (wood, clay, or stone) and pounding it with the fist, a wooden pestle, or, more generally, a stone or clay tamper (Fig. 2). Progressing with rhythmic beating, the potter rapidly obtains a concave form that he/she turns continuously on the anvil or the depression while shaping it. This technique is used throughout the Sahel, from Mali to Egypt (Drost, 1967; Gosselain, 2001; Huysecom, 1992; Sterner & David, 2003). Two main variants have been identified so far, whose spatial distribution across the continent could correspond to distinct historical processes (Gosselain, 2010): (1) *converging pounding*, in which potters pound the clay from the edge of the lump toward its center, and (2) *diverging pounding*, in which they progress from the center toward the edge. In the drawing of a ring-shaped lump, the potter fashions a ring of 20–60 cm in diameter with one or several slab(s) of clay and pulls its wall up with the help of the fingers (Krause, 1985; Lawton, 1967; Livingstone Smith, 2007; Roy, 1989). In most cases, the lower part of the vessel is fashioned later with coils or a pancake of clay, after the upper part has been preformed and is sufficiently dry to be upturned. A variant observed in western Cameroon consists in fashioning the bottom part before the upper one (Nyst, 1996).

The superimposing and drawing of large rings is similar to the previous technique, except that the initial volume is obtained by superposing a series of crown-shaped rings of clay which are then carefully joined. So far, the technique has only been recorded in the southeastern part of Central Africa (Lorenz & Plesner, 1989; de Maret & Bulckens, 1978; Livingstone Smith, 2010; Woods, 1984).

The seven techniques mentioned above are seldom used as such by African potters. The shaping of medium to large vessels usually involves the combination of the last two of these techniques, with the consequence that a detailed comparison of actual shaping processes allows one to identify more than 50 variants across the continent.

In comparison with clay extraction and processing, the most striking aspect about the roughing out process is that it mainly relies on hand gestures. While techniques such as molding and pounding require specific tools and devices, it is especially the artisan's hands and fingers that act during the major part of the shaping process. Gestures associated with the roughing out process also stand apart because of their relatively specialized character. Few relations exist with other activities at this level and only body postures (e.g., working while bending over the rough out or sitting on the ground with legs wide apart) may find an echo in other domains than pottery making.

The reliance on specialized gestures has been identified as a crucial factor for explaining the frequent stability of shaping technique through time and space, as well as the possible coincidence between techniques and major social boundaries such as language, socio-professional groupings, or political units (Fowler, 2008; Gosselain, 2000, 2002). Their mastery involves a close interaction between two individuals and a training period that may span over several years, so that motor habits would be more resistant to change than other stages of the manufacturing process. Recent studies have showed, however, that borrowing processes may also affect the shaping stage (Gelbert, 2001; Gosselain, 2008; Sterner & David, 2003). Another explanation could be that since potters frequently view shaping techniques as an inheritance and an index of their social affiliation, they develop a conservative attitude in regard to the transmission of technical practice at this level of the manufacturing process. This is the case among female potters of the Songhay blacksmith group in Niger, who have acquired the molding technique from their Bella neighbors (considered as former slaves) but have chosen to pass on their own pounding technique ("the true Songhay technique") to their daughters.

Preforming

Carried out in continuation of the roughing out operations, this stage aims at giving the vessel its desired shape. To this end, potters scrape and smooth the wall with a series of tools, exercising gradual pressures in order to deform the clay material.

To round off the body and make it bulge, potters scrape the outside and inside walls while supporting the wall with the other hand. The tools used for scraping the inside surface have a rounded or spherical form: rounded off pottery sherds, pieces of calabash, pods, large seeds, nuts, shells, or spoons. Moved horizontally or obliquely, they do not generate much displacement of clay since internal scraping aims essentially at modifying the shape of the body. Outside scraping and smoothing operations, on the other hand, allow the potter to mask irregularities and to heighten the vessel through the displacement of a rather large amount of clay. Such operations are typically carried with flat and oblong tools, such as flat sticks, spatulas, bones, blades, pods, shells, or corncobs.

Forming the neck may be achieved with different techniques, either in continuation of preforming the body or after having added one or several coil(s). A first technique consists in bending the upper part of the wall through horizontal smoothing of the inside wall. In this case, the potter exercises an increasing pressure on the smoothing tool, while supporting the wall with the other hand, until the appropriate shape is obtained. Another technique consists in smoothing the outside wall of the vessel horizontally

Ceramics in Africa, Fig. 3 Forming the neck and the lip of a vessel with the fingers. A constant pressure is exerted on the wall while the vessel is rotated slowly with the other hand (Photo by Olivier Gosselain)

with a tool whose curvature corresponds to that of the neck. Rounded off sherds or calabash pieces are typically used to that aim. A last technique consists in pinching the rim between the fingers (directly or with the help of a leaf, a rag, or a piece of leather) and rotating the vessel slowly with the other hand while exerting a constant pressure on the rim and progressively tipping up the hand toward the exterior (Fig. 3).

Finally, some potters form the lip of the vessel through constant pressure between fingers – or with the help of any supple material – as in the neck-forming method described above. Depending on the position of fingers, the pressure exerted, and the materials used, lips may acquire a rounded or sharp profile or bear a groove. The rim may also be shaped through smoothing with a flat or slightly concave tool such as a spatula, a stick, a bone, or the nervure of a large leaf. Here also, the potter usually rotates the vessel while exerting a constant pressure on the tool or, alternatively, moves the tool itself on the rim. A last method consists in adding one or several coil(s) above the rim or on its side and smoothing it with fingers or a supple material.

The individual dimension of preforming operations must be stressed. While frequently sharing a pottery tradition with a larger group of people, individual potters often develop idiosyncrasies at this level of the manufacturing process, through the specific ordering of operations and the way tools or fingers are used (Kaneko, 2007). Minute variations in profiles – neck, lip, handle, or base – are also likened to "signatures," which can be recognized as readily by eye as by touch (Gosselain, 2002, pp. 113, 115).

Another striking characteristic of the preforming stage is its permeability to innovation. Starting from simple and common forms, artisans are able to innovate in order to meet new demands (e.g., flowerpots, moneyboxes, stills, or incense holders) or to modernize the aspect of their products (Argenti, 1999). This explains the current appearance of a new generation of flat-bottomed pots fitted with handles, which are faithful copies of the aluminum pans produced in urban environments. The production of such vessels may also allow individuals to position themselves as experts and agents of modernity within their community.

Decoration

Decoration occurs either after shaping, while the paste is still wet, or after drying or even firing. In the first case, the techniques used belong to four large categories: (1) grooving, (2) incising, (3) impressing, and (4) appliqué.

Grooving consists in tracing lines or figures on the surface of the vessel with the fingers or a tool with a rounded or sharp extremity: sticks, stalks, thorns, ends of calabash scrapers, sharp stones, bones, shells, nails, bicycle spokes, bracelets (drawn on the surface), bundles of stalks or thorns held between finger or driven into a clay ball (Fig. 4), hair combs, and indented pieces of calabash.

Ceramics in Africa, Fig. 4 Decorating a vessel with a comb-like device (Photo by Olivier Gosselain)

Incising is similar to grooving, except that the tools used have a sharp cutting edge so that clay surfaces are actually incised. Such tools include knives, spearheads, or scraps of metal.

Impressing is done with distinct tools and methods. The simplest is to press any kind of device or material (fingers, natural objects, sticks, combs, or carefully designed wooden or iron stamps, as those used in the Inland Niger Delta; Gallay, Huysecom, & Mayor, 1998), in order to make a single impression that may be subsequently repeated on the surface. Another method consists of pressing and rocking convex devices such as blades or indented combs and bracelets on the surface and obtaining zigzag-like rows of impressions. Rouletting is a third technique, in which natural objects (corncobs, shells, fish vertebrae, plant parts) or roulettes (made by carving wood or twisting, knotting, braiding, coiling, or wrapping fibers) are rolled on the vessel's surface to obtain regular patterns (Haour et al., 2010).

Appliqué corresponds to any kind of clay elements added to the vessel surface, e.g., coils, buttons, spikes, and human or animal figures.

Decoration made on dry and hard surfaces comprises painting and specific surface treatments. The most usual ones consist of applying a slip made of iron-rich clays, crushed beforehand on a stone or in a mortar, and subsequently sieved and diluted in water. The application is made with the hand or a rag. In many instances, slipped surfaces are then carefully polished with round stones or strings of seeds (mostly from baobabs) or cowries. The resulting effect, after firing, is a dark-red and shiny surface. Polishing may also be done on unslipped surfaces or with graphite, as among several South African populations (Bell & Calder, 1998; Fowler, 2008; Lawton, 1967).

Painting occurs either before or after firing. In the first case, by far the most common, it is done with various mineral pigments diluted in water and occasionally mixed with gum arabic, salt, or sugar, all elements that are said to favor adherence on vessel walls. Pigments are applied with a feather, a millet ear, a stalk, or a stick with a crushed or rag-wrapped end. In southwestern Niger, Bella and Zarma potters use a blade for drawing thin lines and motifs (Fig. 5). Postfiring painting is essentially observed in South Africa or in modern contexts, where vessels are aimed at tourist or city markets. Potters then use industrial paints and inks.

Regardless of the techniques, tools, or materials, a striking feature of decoration is the casual way in which most potters talk about it. Decoration would essentially be a matter of "simple embellishment," "like a hairstyle or clothes," the main function of which is to "attract the customer's eye." In some cases, even the aesthetic function of decoration is questioned, as when potters explain that roulette impressions are simply a matter of modifying wall texture to prevent pots from slipping when manipulated (Bredwa–Mensah, 1996; Priddy, 1971).

Ceramics in Africa, Fig. 5 Applying a mineral paint with the help of a blade (Photo by Olivier Gosselain)

This does not mean that artisans proceed randomly, outside rules, or reference frameworks. On the one hand, pottery decoration is but an ornamental manifestation among others in a given context. Aesthetic choices may be influenced or even channeled by practices unrelated to pottery making. For example, there exist numerous parallels between vessel ornamentation and tattooing or scarification (Barley, 1994; David, Sterner, & Gavua, 1988; Ritz, 1989), as well as architecture or other elements of material culture (baskets, gourds, aluminum pots). On the other hand, if decoration is obviously open to innovation (e.g., the current vogue of painted inscriptions in West Africa), change mostly affects the components of the decors, rather than their organization or "grammars." Interestingly, the later could be related the symbolic function of decoration or the expression of collective identities (David et al., 1988).

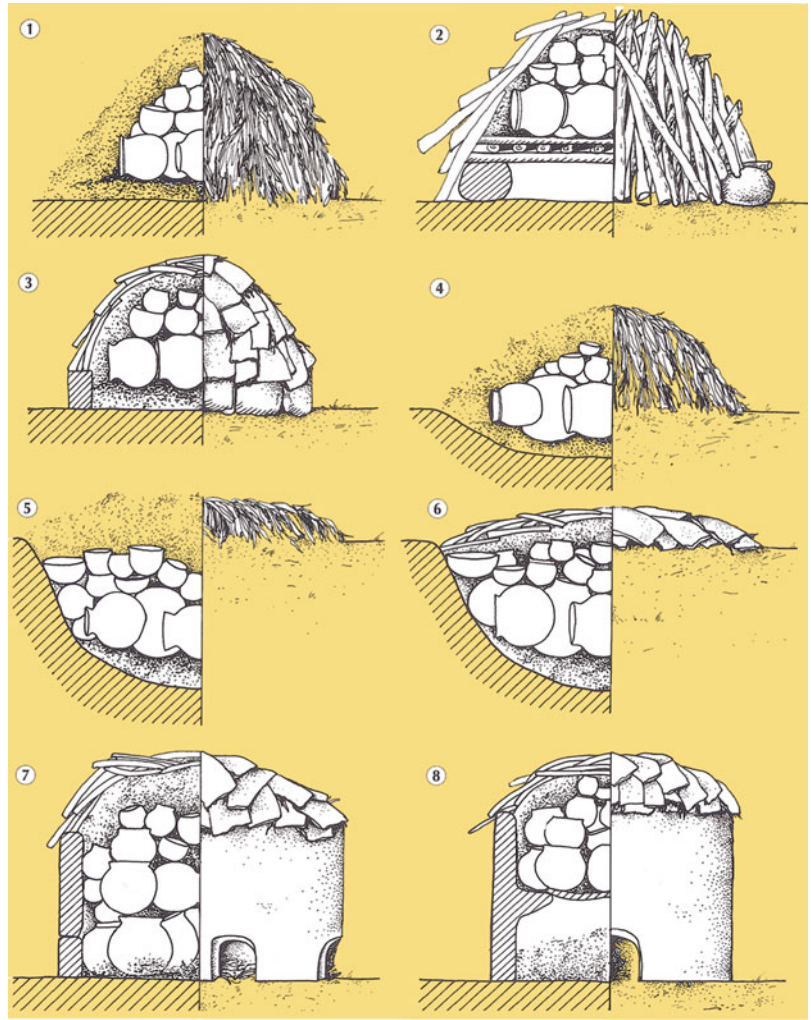
Drying

There exists a broad palette of practices and attitudes in regard to drying. Some potters deem it necessary to place the wares in the sun during the early stage of drying, while others take great care to shelter them during the first hours, the first days, or even the whole drying process. Similarly, some may wait several weeks or several months before firing the vessels, while others do it after 2 or 3 days. While drying periods are often shorter in dry areas than in tropical areas, variations seem essentially related to personal conceptions and schedules, rather than climatic variations or the chemical and physical characteristics of raw materials. Thus, potters who make vessels on demand or frequent weekly markets generally resort to short drying periods. If necessary, wares cracked from too fast a drying are simply repaired with fresh clay.

Such flexibility in drying procedures is due, in part, to the accommodating nature of the raw materials used in Africa. But it may be reinforced through the use of preheating techniques that allow the gradual evaporation of residual water. For instance, pots may be placed around or above a cooking earth (Gosselain, 2002, pp. 145–146; Priddy, 1971; Woods, 1984), on glowing embers (Kanimba & Bellomo, 1990; Mercader, Garcia–Hera, & Gonzalez–Alvarez, 2000), or on a rack-like structure below which a fire is kept going, as among several Kongo groups from Central Africa (de Maret, 1974; Mpika, 1986).

Firing

Although the emphasis will be put here on fuels and structures, several other aspects of firing may be taken into consideration, including the scheduling of firing events, the location of firing structures, the way vessels and fuel are positioned within the structure, the overall firing schedule (duration, refueling, way of assessing the degree of firing of the wares), or the identity of people taking part in the operation.



Ceramics in Africa, Fig. 6 Firing structures used in Africa: (*1*) bonfire, (*2*) elevated bonfire, (*3*) bonfire with isolation, (*4*) depression, (*5*) pit, (*6*) pit with isolation, (*7*) oven, and (*8*) updraft kiln (Drawing by Yvette Paquay)

Fuel

As summarized by Livingstone Smith (2001, p. 993), almost all categories of combustible materials are used for firing pottery in Africa, from sawdust to rubber tires. Used independently or combined in various proportions, they may be grouped into three main categories, corresponding roughly to those made by the artisans themselves when asked about their conception of "appropriate" and "inappropriate" fuels: (1) manure of cows, donkeys, camels, or horses; (2) light materials (dry grass or cereal stalks, cereal chaff, palm fronds, leaves, twigs, barks, or roots); and (3) heavy materials (branches and logs from dozens of tree species).

Neither the firing structure nor the firing conditions possibly sought by potters seem to impose restrictions on the selection of fuel materials. With the notable exception of manure, whose combustion is slower, all the fuels used throughout Africa allow potters to obtain similar firing schedules and temperatures.

Structure

Eight firing structures are documented in Africa (see details in Drost, 1967; Gosselain, 2002, pp. 153–162): (1) bonfire, (2) elevated bonfire, (3) bonfire with isolation, (4) depression, (5) pit, (6) pit with isolation, (7) oven, and (8) updraft kiln (Fig. 6).

Bonfires are the most commonly used structures in Africa. Pots are placed on a bed of fuel, at ground level, and covered with another layer of fuel. Such structures vary tremendously in size (50–250 cm in height and 50–700 cm in diameter), firing duration (from 20 min to several hours), as well as the number of vessels fired at once (from 1 to 500). The number pieces may depend on the stock available at the time of firing but also personal conceptions. For example, some Gbaya potters from Cameroon deem it impossible to fire more than one to three vessels at once. They thus multiply firing sessions or construct several bonfires side by side.

So far, elevated bonfires have only been observed in the Great Lakes region, among the Twa of Burundi and Rwanda and the Konjo of Uganda (Célis & Nzikobanyanka, 1984). The technique consists in placing vessels on elevated rack-like layers of branches placed on four or five big stones and covering them with fuel. During firing, they fall gently on the ground as the branches gradually burn down.

Bonfires with isolation differ from simple bonfires in that a layer of fireproof materials – sherds, enamel wares, sheets metal – is placed either between the vessels and the upper layer of fuel or upon the whole structure. In the first case, the aim is to avoid color variations caused by contacts between fuel and vessel surfaces. In the second, the aim is to shelter the structure from the wind.

Depressions are shallow structures dug in the ground (between 20 and 40 cm depth) in which vessels stand partly above the ground when having been placed on the fuel bed. Their shape is circular, oval, or rectangular, with diameters (or sides) ranging from 100 to 500 cm. As for bonfires, important variations are observed in the number of wares fired at once and the duration of the firing. Variations also exist in the way vessels are positioned within the structure. For instance, while most potters place them horizontally or vertically, some place them upside down on the bed of fuel, in order to obtain a dark and shiny internal surface, as among the Zaghawa of Sudan (Tobert, 1984) or Hausa and Kanuri of Niger.

What differentiates pits from depressions is that, in the former structure, vessels remain below the ground surface after having been placed on the fuel bed. Their depth always exceeds 50 cm and may reach as much as 100–150 cm, for a diameter ranging from 50 to 400 cm. Another difference pertains to the duration of the firing, which is often several hours long. In a variant observed among Bamileke Fe'fe' from western Cameroon (Gosselain, 2002) and Kongo Manyanga from Congo (Mpika, 1986), the wares are placed on a rack-like wooden structure standing above the pit and gently tipped in the hole in the course of firing.

Pits with isolation resemble bonfires with isolation in that a layer of fireproof materials is placed either on the vessels or on the upper layer of fuel. This technique is commonly used in southern Africa (Krause, 1985; Lawton, 1967) and throughout the Sahel area, from Senegal to Sudan. Here, the firing usually lasts a whole night, even though the fire actually burns for a few hours.

Ovens are wall-enclosed structures within which vessels are not separated from the fuel. Such structures have only been documented in West Africa. They are made of mud, with a height of 50–180 cm and a diameter of 100–400 cm. The base of the wall has one or several hole(s), through which fuel (usually stalks or grasses) is charged during firing. 20–200 vessels may be fired at once in such structure. They are piled and subsequently covered with fuel and/or a layer of sherds. A simpler oven technique, observed among some Yoruba of Nigeria (Fatunsin, 1992, pp. 39–40) and Bariba of Benin, consists of firing vessels in a bottomless jar placed on mud bricks upon a small fire. Such technique is only used for small pieces.

Updraft kilns are particularly rare in sub-Saharan Africa. So far, they only have been observed in western Nigeria, among the Nupe of Bida (Nicholson, 1934; Vernon-Jackson, 1960) and the Yoruba of Abeokuta (Fatunsin, 1992). While such firing structure is constituted of a circular mud wall – as ovens – fuel is placed in a distinct chamber and separated from the

vessel with sherds or a perforated clay plate. They are in fact strongly reminiscent of the fish dryers used along the River Niger, within and to the north of the Nupe area.

Measurements made in the field show a considerable homogeneity in firing conditions, despite the variety of fuels and structure used throughout the continent. Whether in regard to temperature rise, maximum temperatures, or the time of exposure to specific temperature thresholds, each technique allows for similar results (Livingstone Smith, 2001). Such homogeneity echoes the way in which potters determine the completion of the firing process: in most instances, they retrieve the vessels or stop refueling when vessels' walls become incandescent.

There exist multiple relationships between firing techniques and techniques used in the realm of food processing (Gosselain, 2002, p. 165). But not with metallurgy, even in societies where male blacksmiths and female potters belong to the same endogamous subgroup. The fact that both activities are respectively practiced by different genders and in different circumstances would seem to hamper technical transfer. As other stages of the manufacturing process, firing is also surrounded by a series of prescriptions and prohibitions. Yet, they are both less numerous and less influential in technical terms, as they aim essentially at avoiding "evil" or "impure" individuals.

This worry stems from the public and collective character of the firing process. In many regions of Africa, artisans associate with relatives, friends, or neighbors for firing their wares. Such associations do not only help in alleviating their work but also meeting scheduling constraints (e.g., the existence of weekly markets) when only a few firing locations are available. Interestingly, communal firings often give rise to micro potting communities when artisans start to regroup on a regular basis. Operating within broader communities, they are characterized by the existence of close social bonds between members and the development of specific technical practices not necessarily limited to the firing process (Corniquet, 2011).

Postfiring

In many regions of Africa, vessels are subjected to various treatments after firing, either when retrieved red hot from the fire or after having cooled off. Aiming at improving the physical characteristics and/or appearance of vessels, postfiring treatments may be grouped into five categories: (1) organic coating, (2) resin application, (3) smearing, (4) smoking, and (5) water sprinkling or soaking.

Organic coating is by far the most common treatment. It consists of coating the surface with an organic mixture made from parts (bark, fruits, leaves, branches, roots) of several dozen tree species, the most common of which are *Bridelia ferruginea*, *Bridelia micrantha*, *Parkia biglobosa*, *Parkia filicoidea*, *Diospyros mespiliformis*, *Ximenia americana*, *Pterocarpus angolensis*, and several *Acacia* and *Syzygium* subspecies (see details in Drost, 1967, pp. 174–182; Gosselain, 2002, pp. 184–190). After having been crushed, the material is boiled in water (decoction), put into hot water (infusion), or soaked at ambient temperature (maceration). Application is done by immersing hot vessels in the mixture, sprinkling it on the walls, or smearing the surface with the help of a series of brushlike tools. Alternatively, cooled off vessels are coated with the help of a rag. Besides having a decorative purpose, organic coatings are said to have strengthening and waterproofing effects.

Resin application is solely aimed at waterproofing the vessels. In this case, the inside surface is coated with resin extracted from several tree species – e.g., *Canarium schweinfurthii*, *Copaifera demeusei* or *mildbraedii*, various *Acacia* species, *Euphorbia candelabrum*, *Dodonea viscosa*, and *Guizotia abyssinica* – either by melting it directly in the vessel or pouring it in after melting. The vessel is then rotated rapidly for ensuring a homogeneous surface coating.

Organic materials may also be smeared on the surface or cooked in the vessel in order to strengthen or waterproofing them: leaves of *Ricinus communis* or *Sida rhombifolia*, oil or sap from *Raphia vinifera* or *Elaeis guineensis*, fruits, fibers, roots, cereal husks, milk, porridge,

or cow dung (see examples and details in Gosselain, 2002, pp. 191–192).

Smoking aims at covering the vessel surface with wood tar in order to give it a black shiny aspect – and according to several potters, improving their strength and waterproofing. To that aim, vessels retrieved red hot from the fire are usually buried in organic materials such as grass, cereal husk or chaff, animal manure, fruit pods, and bark or wood shavings (see examples in Gosselain, 2002, pp. 192–193). Another technique, observed in the Great Lakes region and South Africa, consists in maintaining vessels above a small fire (Armstrong, Whitelaw, & Reusch, 2008; Fowler, 2008; Trowell, 1941).

Lastly, vessels may be immersed in, or sprinkled with, freshwater or boiling water (see examples in Gosselain, 2002, p. 193). Here again, the aim is to waterproof and strengthen the wares.

As with clay processing or firing, artisans often emit strong views about the choice of ingredients, preparation recipes, or application techniques. As diverse – and even antagonistic – as they are, they seem to follow similar logics. For instance, sub-Saharan potters use at least 50 different plant species for making organic coatings, but few of them know about the existence of other plants than the ones they use, and most believe that there is simply no alternative to their choice. The same applies to the preparation of the plant parts or the application technique. Seen from a comparative and analytical perspective, however, all choices are perfectly justified from a technical or aesthetical point of view. The chromatographic analysis of various fruits and barks used in sub-Saharan Africa indeed reveals the presence of a specific category of tannins, the procyanidins, with excellent coloring and waterproofing properties (Dialo, Vanhaelen, & Gosselain, 1995).

The most striking aspect of the postfiring stage is its connection with many other domains of activity. For example, most of the plant species exploited by potters are also used as food, dyes, basketry materials, waterproofing materials for wall and pavements, and, above all, pharmacopoeia. This last domain reveals interesting ties, as the illnesses and injuries treated with the help of preparations similar to those used by potters are mostly characterized by discharges (Gosselain, 1999, 2002, pp. 197–198, pp. 210–211): wounds, diarrhea, gonorrhea, hemorrhage, menorrhagia, ulcers, etc. Pots are thus treated as human bodies, and reversely. Similarly, postfiring treatments are often connected to birth and circumcision rites. What is at work, here, is the materialization of an extremely widespread association between pottery making and human beings (Armstrong et al., 2008; Barley, 1994; David et al., 1988; Gosselain, 1999; Ritz, 1989) that seems to channel potters' behavior in relation to the choice of ingredients as well as processing and application techniques.

This fact illustrates perfectly why a *chaîne opératoire* cannot be reduced to mere actions on matter. As stressed by Lemonier (1991) and many other scholars, techniques do not solely aim at transforming materials or acting upon the material world. They also respond to a series of social, political, economical, and symbolic concerns, whose echo may be found at any level of the manufacturing process as we have seen throughout this article.

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Ceramics in Burma

Myo Thant Tyn
Kyeemyindine Township, Yangon Region, Myanmar Ceramic Society (MCS), Yangon, Yangon Region, Burma (Myanmar)

Prehistoric Earthen Wares

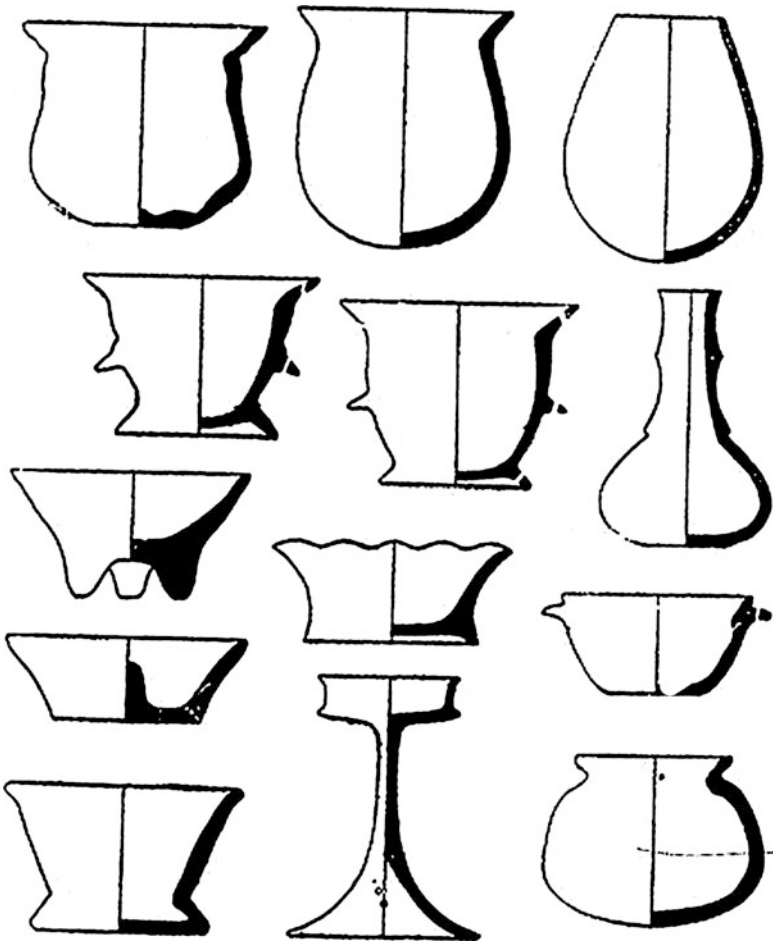
***Late Palaeolithic Age*:** The prehistoric tradition of Myanmar (Burma) earthenware could be traced back as far as 13,400 ± 200 years before the present (BP) with some simple cord-marked potsherds, an earliest Hoabinhian culture or earlier than the Spirit Cave (Thailand), from the excavation of Padah-Lin caves in the Ywa-ngan Township (Shan State) in January 1969. The late Anyathian (12000–6000 BP) culture site in Myanmar belongs to the late Palaeolithic Age (75000–9500 BP).

***Neolithic Age*:** The corded earthenware culture of the Neolithic Age (6000–4000 BP) was discovered at various places within the great basin where the Chindwin and Ayeyawady rivers flow from Kani down to Letpanchebaw and Thegone. Red-painted pottery from Halin and Twintaung are also included in this culture. Other prehistoric earthen pottery has been found, mostly by excavation, in Taungthaman (late Neolithic) (Fig. 1), and Nyaunggan (1500–300 BC) (Fig. 2).

***Forming Technique*:** Much of the pottery recovered was plain and undecorated, being formed by coiling and paddling (without wheel) fine-grained clay tempered with sand which had turned a buff colour on firing. The turning wheel was supposed to be invented from about 5000 BP and found in continued use in about 950 BC (excavated finding at Nyaunggan). Forms comprise a variety of bowls with inverted, everted, and perforated rims and rounded, ringed, and tripod bases. A few have perforated lugs on the body while others are set on flaring foot-rims.

***Uses*:** Such bowls probably served as oil lamps and receptacles for food, water and flour for both domestic and ritual purposes. In Nyaunggan, Bronze Age artifacts, including earthenware pottery has been excavated; among these some interesting sets of pots that might possibly have been used for distillation for alcohol or fragrance were found (Fig. 3). Consequently, small cylindrical pots something like beer cans were also found in an excavated site at Samon Valley (Bronze-Iron Transition Age) could be regarded as a distillate container for generating evaporated cooling effect. Ceramic earthenware in various forms also played a very important part in the lives of Myanmar people. From the late Palaeolithic period to historic times earthenware had been used for storing and cooking food, for ceremonial and religious purposes, and also for building and decorating houses, palaces, shrines and city walls. From birth to death, earthenware had a significant role in Myanmar. In many cases in ancient times, earthenware was buried in the grave so as to accompany the dead to other existences.

***Decoration/Design*:** Although simple cord-marks are possibly the earliest design decorated on pottery surfaces since late Anyathian culture in Myanmar, better techniquess and varieties of decoration or design seemed to appear in about 9000 BP. The technique for decorating earthenware changed and diversified in Myanmar since that time and falls mainly into two groups, incised

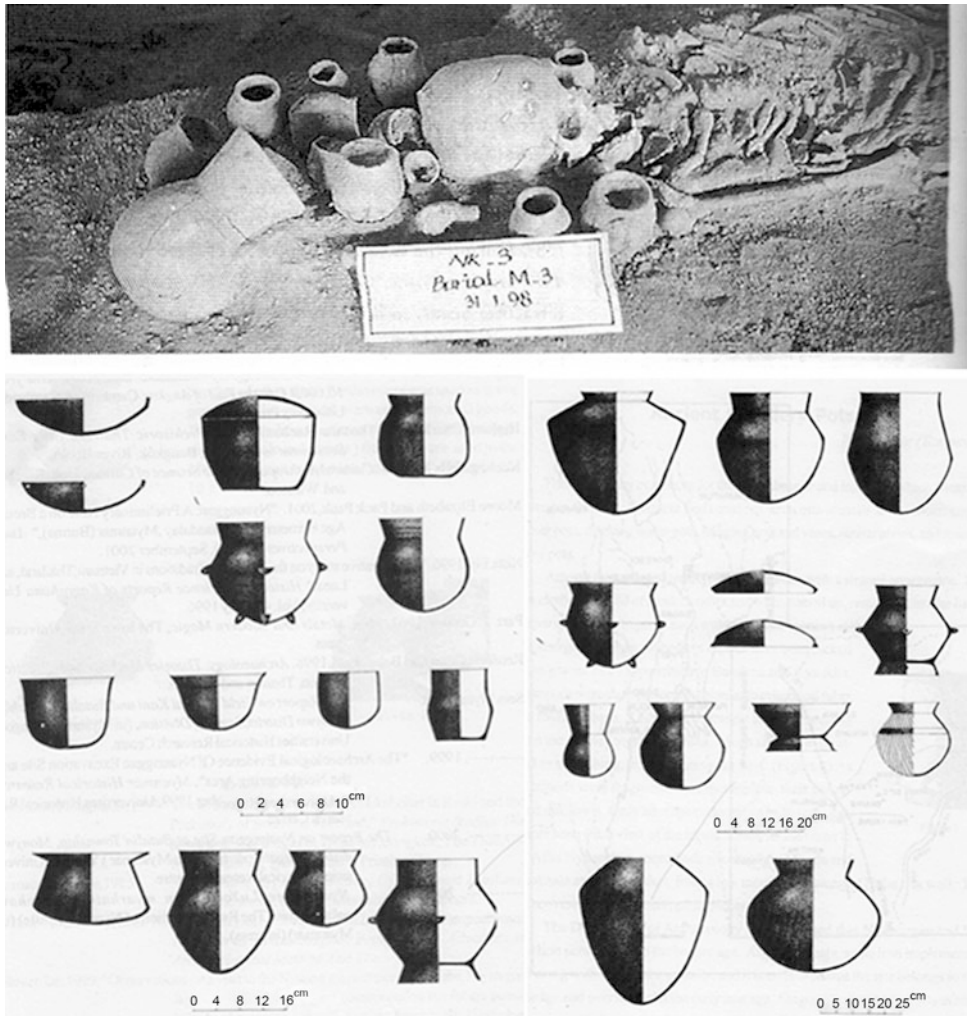


Ceramics in Burma, Fig. 1 Neolithic earthenware from the west bank of Lake Taungthaman (Amarapura) (Than Tun "Pottery in Burma, 1972")

and impressed. The incised technique used a sharp or pointed tool, a comb or a shell to cut or punctuate the required pattern on the clay surface. In the impressed technique, the pattern was impressed into the surface of clay rather than cut or appliquéd. The incised technique was normally used for lines and curving patterns whereas the impressed technique was used for the rest. Different tools and different methods were used in the impressed technique. A paddle wrapped with cord, basket, net or fabric was used to make impressions on the clay surface and such products are called cord-marked, basket-marked, net-marked or fabric-marked pottery. The other type of paddle impressed method was carved-paddle-impressed where patterns were carved on the surface of the paddle and made impressions on clay surface layer by beating with the paddle. The other one was the stamped-impressed method where the stamp with pattern was pressed onto the clay surface. The roulette method was another impressed technique where a roller with patterns (called roulette) was pressed and rolled on the clay surface.

Protohistoric and Transition Period Earthenware

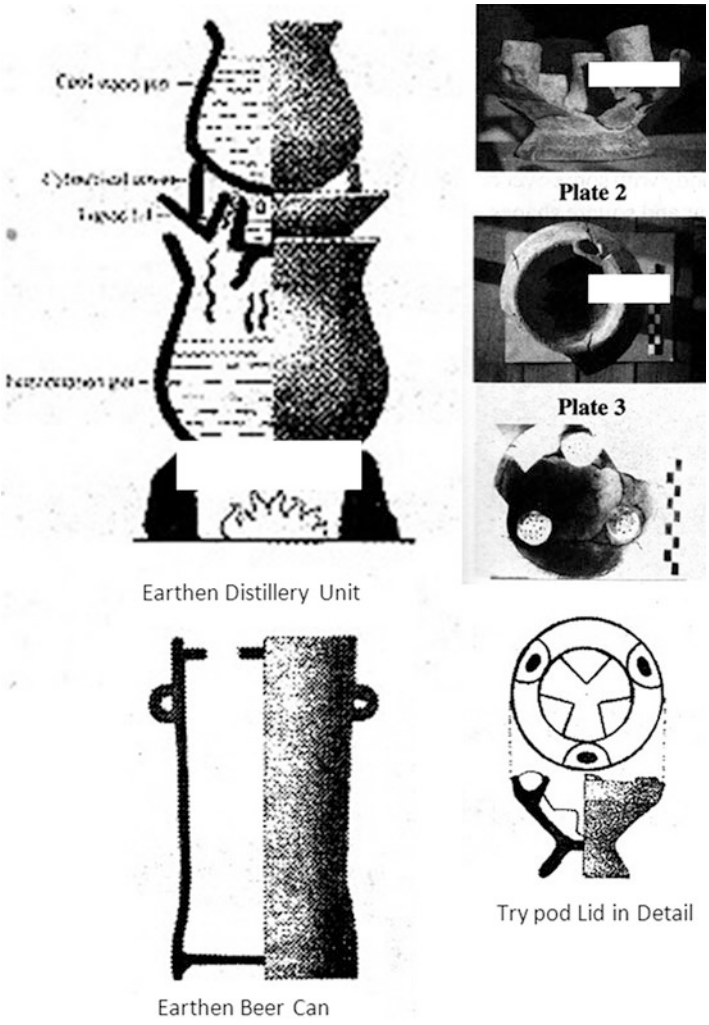
***Analysis Through Design*:** Comprehensive study of design from the assemblage of 3,000 potshards from Taungthaman, Beikthano, Halin, Tagaung, Bago, Mrauk-U, Amarapura and Twante reported by various scholars was conducted. Although these designs look simple enough as individuals, when studied collectively in large numbers some



Ceramics in Burma, Fig. 2 Earthenware excavated from Nyaunggan in association with burials containing bronze weapons (Ni Ni Myint, 1998; Sein, 2003)

cultural link can be deduced for a better understanding of the prehistoric and protohistoric culture of Myanmar.

***Neem-Leaf Design*:** Analysis of the Neem-leaf design is an example for deduction. Through close analysis referring to the above technique the design could be classified into two categories, geometric and zoomorphic decorations. In the geometric group carved-paddle-impressed Neem-leaf design was used the most (about 50 %). Out of Neem-leaf pattern shards the majority was collected from Delta (Tawnte and Bago) (Fig. 4). Only a few were observed in upper Myanmar. This was also found to be a missing link for the migration of carved-paddle-impressed (Neem-leaf pattern) pottery tradition into island Southeast Asia proposed by the eminent scholar Dr. Solhein II. He said that, "the movement of carved-paddle-impressed tradition was towards the east from India by the way of Burma as early as 2000 years ago so it may have spread through the Malay maritime world from India or Burma". Now it is clear that Twante could be the link in solving the migration problem of this tradition from India to island Southeast Asia through via Myanmar. Moreover it



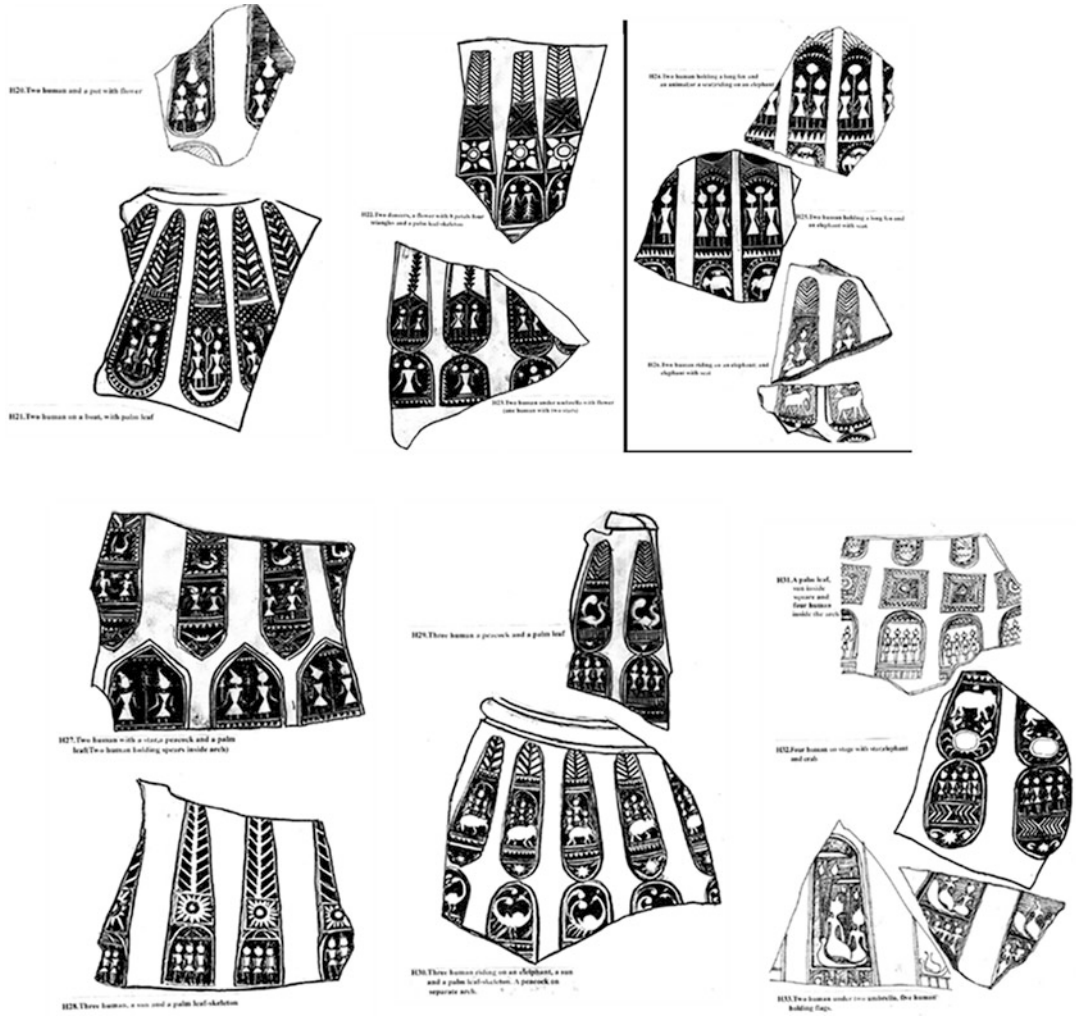
Ceramics in Burma, Fig. 3 Earthenware distillation unit excavated from Nyaunggan

could also infer that Neem leaf type pottery tradition started in Twante as early as 2000 BP and then migrated to upper Myanmar.

Historic Earthenware and Glaze Ware: Pyu Period

The Pyu period is the transition from the prehistoric to the historic civilization of Myanmar; it flourished from about third Century BC to about ninth Century AD. During a millennium Pyu people were able to accomplish indigenous development of Pyu towns and cities such as Samon Valley (fifth Century BC-first Century AD), Beikthano (second Century BC-fifth Century AD) (Fig. 5), Tagaung (earlier than first Century AD), Halin (second Century AD-ninth Century AD) (Fig. 6), Sriksetra (third Century AD to ninth Century AD) and Pinle (Mai-mau) (fifth Century AD) from small prehistoric villages in a way that was not previously possible in Southeast Asia. There were also numbers of self-regulating villages and towns of Pyu people outside the cities area. These Pyu people left an impressive record of their lives and deaths in the archaeological evidence.

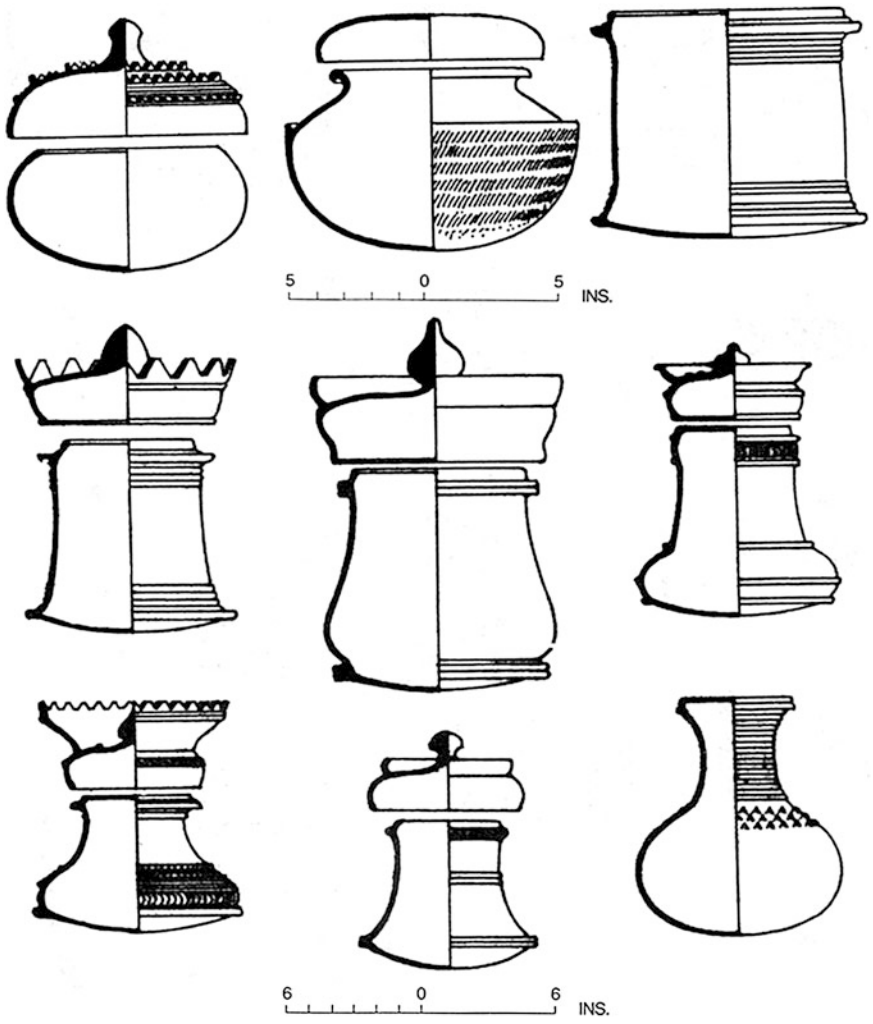
***Excavation of Pyu Cities*:** A series of excavations was conducted at important Pyu cities by the Archaeological Department at Beikthano (since 1958), Halin (since 1963) and Sriksetra (initially in 1907 and since 1963). They collected a considerable amount of information on ceramic



Ceramics in Burma, Fig. 4 Neem leaf (carved-paddle-impressed tradition) design on earthenware pottery shards from Twante

artifacts. As these artifacts are specifically related to the Pyu culture, they are being employed as an allegoric tool for tracking ancient Pyu. Earthen artifacts such as burial urns, bricks with marks/finger-scratches (Fig. 7), potter marks/Pyu-alphabet (Fig. 8), earthen and glass beads, earthen votive tablets and earthen seals obtained from the archaeological excavations are unique tools for identification.

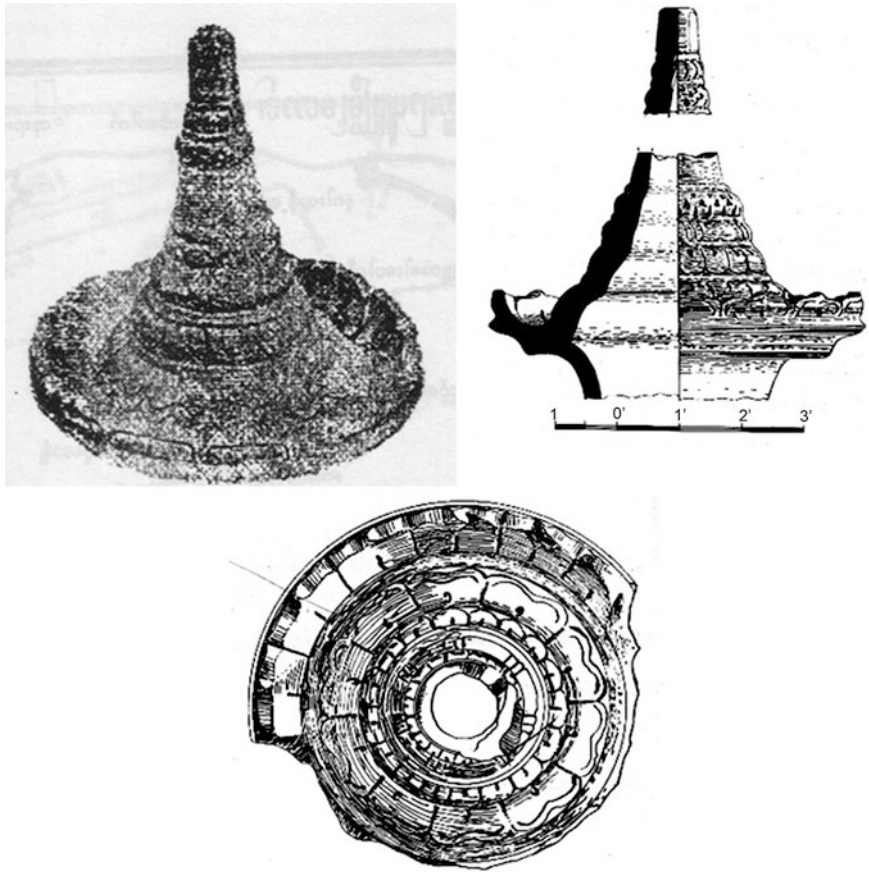
***Glazed Ceramics in Pyu Period*:** Although many earthenware objects emerged from excavations glazeware is still missing and has not shown up as archaeological evidence in any of these Pyu sites. However evidence for the existence of glazed ceramics tradition in Pyu period is now in hand. The direct eyewitness is the Ngakywe-Nadaung pagoda (eighth to ninth Century AD) on which tin-lead glazed bricks were inlaid (Fig. 9). From logical deduction based on the evidence [potter marks of Pyu, seventh Century AD stone inscription mentioning Kalathapura (City of Pots) and fifth Century AD dated Buddha bronze image being covered with green glaze], a hypothesis was proposed that Pyu potters might have been the first to employ glazed ceramic technology (possibly low temperature



Ceramics in Burma, Fig. 5 Earthenware excavated from Beikthano (Vishnupura)

lead glaze) in Myanmar at about fifth Century AD or earlier.

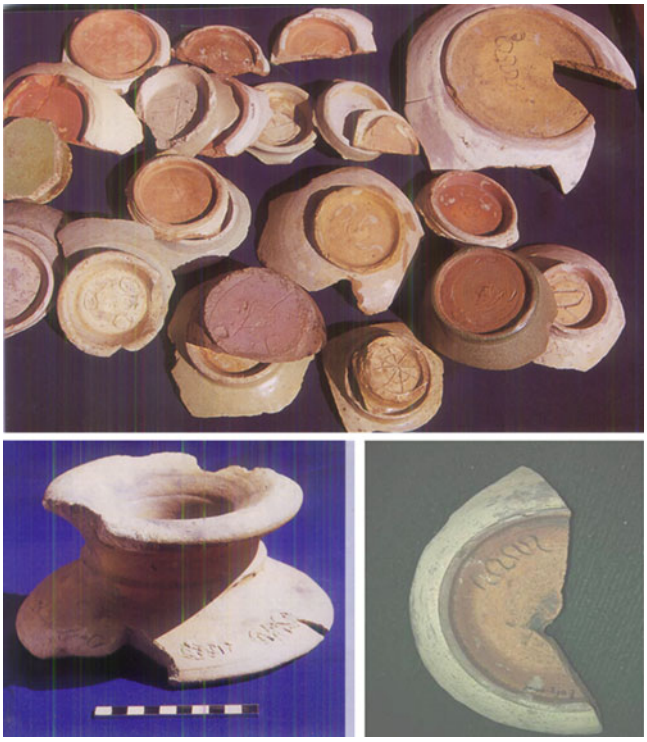
***Revelation of Glazed Ceramic History in Myanmar*:** The history of Myanmar glazed ceramics has just emerged from its obscured existence. Although there was a long tradition of Martaban jars most of the ceramic historians were less enthusiastic about including Myanmar into their study because of the scarcity of ancient production sites. This dormant period stretched along until 1984 when some mysterious green-and-white glazed wares popped up in the Tak and Omkai areas near the Thai-Myanmar border (Figs. 10 and 11). While beautiful green-and-white ware was popular in antique markets the controversy of its origins triggered the enthusiasm of ceramic historians. Being passionate lovers of Asian ceramics, the Japanese brought large amounts of green-and-white wares back home and identified that their origin is Myanmar through lead isotope ratio analysis. These findings aroused the interest of ceramic historians in such a way that the Myanmar Glazed Ceramics tradition suddenly became quite important. Ceramic historians and local enthusiasts joined forces to reveal the ancient Myanmar glazed ceramic tradition so as to elucidate the ambiguity of green-and-white wares.



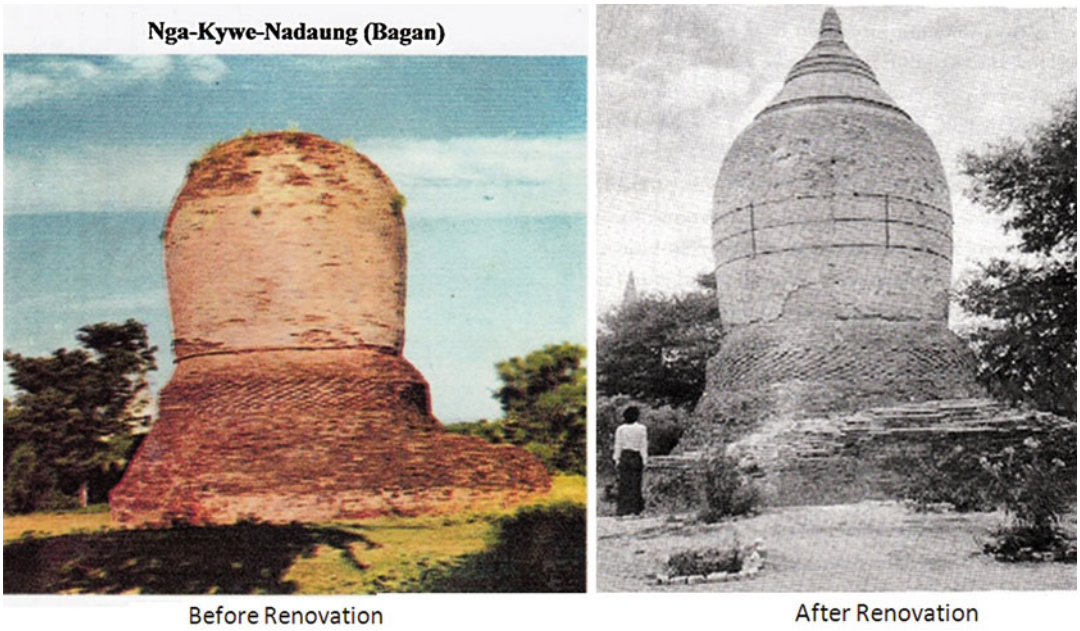
Ceramics in Burma, Fig. 6 Earthenware excavated from Halin

Ceramics in Burma, Fig. 7 Earthenware bricks with marks and finger-scratches

Due to this collective effort about a hundred production sites consisting of nearly 2,000 kilns were discovered in different places such as Lagumbyee (Yangon-Bago Regions); Pathein, Old-Myaungmya and Ngaputaw (Ayeyawady Region); Twante (Yangon Region); Bagan and Inn-Wa (Mandalay Region); Honar (Shan State); and Mrauk-U (Rakhine State). Some



Ceramics in Burma, Fig. 8 Potters marks on pottery



Ceramics in Burma, Fig. 9 Ngakywenadaung Padoga with inlaid tin-lead glazed bricks

Ceramics in Burma, Fig. 10 Tin-lead glazed white ware from Tak-Omki near Thai-Myanmar border

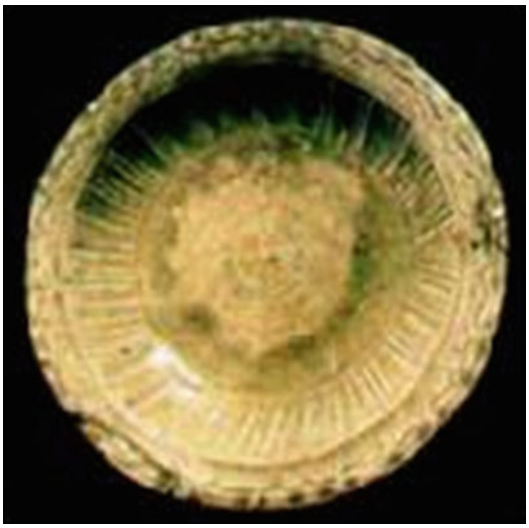
Ceramics in Burma, Fig. 11 Green and white ware from Tak-Omki near Thai-Myanmar border

possible sites were identified in Martaban, Donzayit and Mawlamying (Mon State); Hmawbe and Hlègu (Yangon Region); Hinthada, Maubin and Bogalay (Ayeyawady Region); Pakhangyi (Magway Regin); Chaung-U, Myin-hmwe, Panpin and Myin-mu (Sagaing Region); Keng Tung (Shan State); Vesali (Rakhine State); Tagung (Sagaing-Mandalay regions) where many glazed shards, wasters and supports were found.

Out of these listed kilns few low temperature updraft kilns producing alkaline, lead and tin-lead glazewares are situated in Bago, Bagan, Inn-Wa and Myin-Mu along Ayeyarwady River banks in Central Myanmar. The rest are high temperature crossdraft (surface and inground)

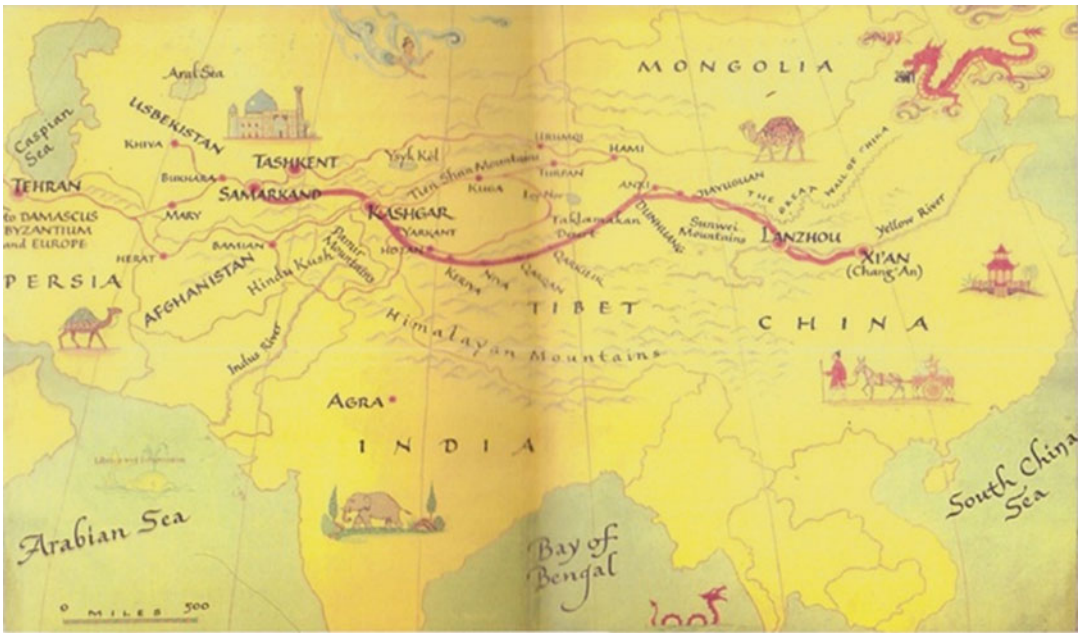
kilns capable of producing lead or tin-lead glazeware and high temperature ash glaze (celadon) stoneware (Fig. 12).

***Low Temperature Glaze Tradition*:** Lead or tin-lead glazeware was fired in an oxidized atmosphere at about 900–1100 °C in updraft kilns. It was generally accepted that low temperature updraft kilns originated in ancient Egypt where low temperature glazes (with lead as flux) were produced in early 4000 BC. The use of tin as an opacifier in lead glaze was also noticed in the Middle East (Persia) since 1100 BC when tin-lead glazed bricks marked with the name of the Assyria king, Tiglath-Pileser, had been found. Therefore it could be deduced that low temperature glaze tradition originated in the Middle East and spread. For East-bound migration, possibly both overland and sea routes of the Silk Roads might have reached Myanmar (Figs. 13 and 14). However since early 109 BC the overland Silk Road had been the conduit for envoys from West (Persia) that might penetrate from India into Myanmar by two routes: one linked to China and the other to Thailand (Dvāravatī), Cambodia (Funan) and Vietnam (Annam). Both routes involved Ayeyawady River which is navigable all the way down to its delta.

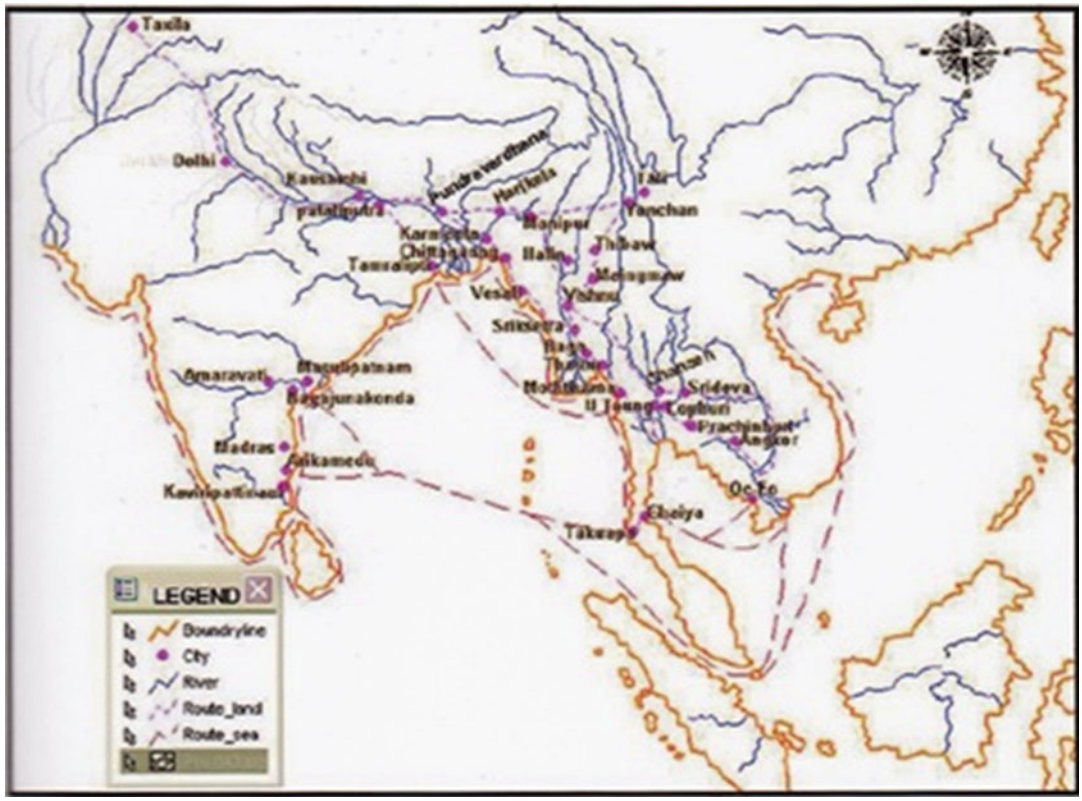


Ceramics in Burma, Fig. 12 Celadon (ash glaze) of Myanmar 15th–16th AD

Since tin-lead glazewares are hardly known in China, the tin-lead glaze tradition of Myanmar possibly came directly from Persia through the inland Silk Road. The presence of turquoise (alkaline) and opaque (tin-lead) glaze-coated



Ceramics in Burma, Fig. 13 The overland silk road



Ceramics in Burma, Fig. 14 Trade routes among Pyu, China, India and SEA in ancient period (Dr. San Shwe, 2008)

bricks inlaid on the eighth to ninth Century AD dated Pyu-type Ngakywenadaung pagoda and excavated finds of turquoise, green, olive green and brown (alkaline, tin-lead) glaze shards from updraft kiln No.1 of Bagan etc. support the technological connection with Persia although the products were locally made. Based on the ancient Chinese chronicles and practical reasoning, Di Crocco postulated that Pyu city with green glaze brick wall mentioned by eighth Century AD Chinese chronicles was some ancient city in the Bagan area. Chronicles also mentioned Pyu people use tiles of lead and tin, silver coins and traded or battered in glazed jars. Bawzaing mine extracted silver as early as sixth Century AD with lead slag as a by-product containing at least 30 % lead and a bit of tin. Therefore a very large glazed ceramics industry must have existed around that period. Since some time is usually needed to attain such production level it is envisaged that Pyu potters might have started their industry much earlier, say fifth or sixth century AD.

***High Temperature Glaze Tradition*:** The high-fired stoneware glaze technology was discovered in the Shang-Yin period (1500–1027 BC) as having its origin in China. Wood ash or lime was employed as a flux in combination with silica and feldspar to produce celadon firing in reduced atmosphere at about 1250–1300 °C in crossdraft kilns. It is believed that celadon technology might possibly have come into Myanmar directly from China through East-Northern route although we do not know exactly when. However there is an indication for probable existence of a celadon manufacturing tradition in Myanmar (Bagan) at about eleventh to twelfth Century (Di Crocco, 1990). In recalling the fact that celadon stoneware from Myanmar (Twante) were being exported to Egypt as early as fifteenth Century AD the said indication is quite plausible.

As mentioned earlier there were signs of active updraft kilns in Central Mainland Myanmar at about sixth Century AD it is quite relevant to assume the indigenous evolution of the updraft kiln into the crossdraft kiln. However there is not enough evidence of transitional kilns in hand yet. Until then a provisional assumption of Chinese connection for crossdraft kilns has to be maintained.

While updraft kilns were mostly situated in the central mainland, crossdraft kilns were widely spread along the outward area of the country such as Rakhine State; Ayeyawady, Yangon and Bago Regions; Mon, Kayin and Shan States. Inground kilns were mostly concentrated in the West and West-Southern parts producing lead and tin-lead glaze wares whereas surface kilns in East and East-Southern parts producing ash glaze (celadon) wears. When and why the whole celadon production (expect Honar, Shan State) was stopped and why lead glaze tradition was dominated until now are questions still to be answered.

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Ceramics in China

Jiazhi Li, P. L. Leung, K. N. Yu and R. Wu

China was one of the earliest countries that possessed pottery, and was also the country that invented porcelain. She has a unique and sustained history of technique development of 10,000 years. The entire development can be summarized by five milestones and three technological breakthroughs. The outstanding achievements in this development constituted an indispensable contribution to Chinese culture (Table 1 and Map 1).

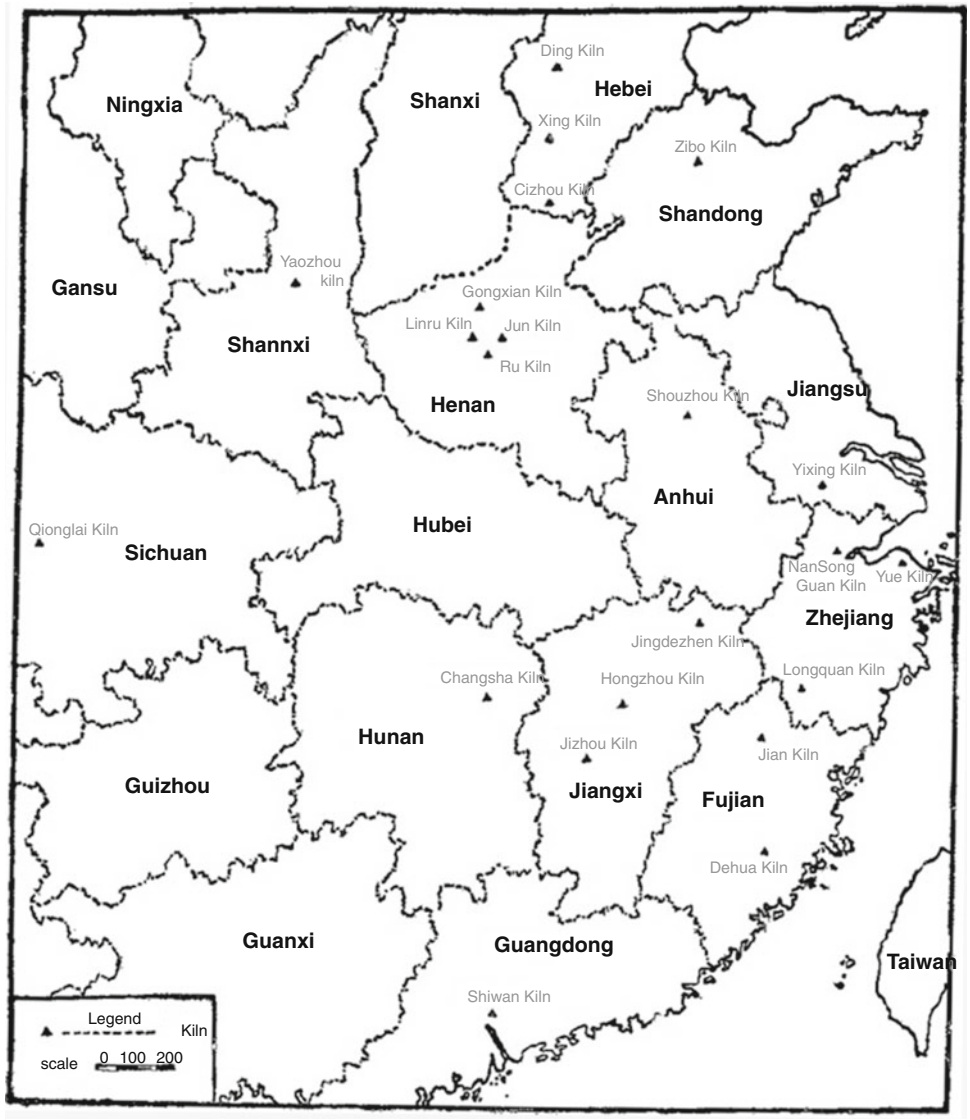
Ceramics in China, Table 1 Chronology of ancient Chinese history

Neolithic period	**6500–1700 BCE**
Xia	2100–1600 BCE
Shang	1600–1100 BCE
Western Zhou	1100–771 BCE
Spring and autumn annals	770–476 BCE
Warring States	475–221 BCE
Qin	221–206 BCE
Han	206 BCE–AD 220
Three Kingdoms	220–280
Jin	265–420
Southern and northern	420–581
Sui	581–618
Tang	618–907
Five Dynasties and Ten Kingdoms	907–960
Sung	960–1279
Yuan	1279–1368
Ming dynasty	**1368–1643**
Hongwu	1368–1399
Jianwen	1399–1403
Yongle	1403–1424
Hongxi	1425–1426
Xuande	1426–1435
Zhentong	1436–1450
Jingtai	1450–1457
Tianshun	1457–1465
Chenghua	1465–1487
Hongzhi	1488–1505
Zhengde	1506–1521
Jiajing	1522–1566
Longqing	1567–1572
Wanli	1573–1619
Taichang	1620–1621
Tianqi	1621–1627
Chongzhen	1628–1643
Qing dynasty	**1644–1911**
Shunzi	1644–1661
Kangxi	1662–1722
Yongzheng	1723–1735
Qianlong	1736–1795
Jiaqing	1796–1820
Daoguang	1821–1850
Xianfeng	1851–1861
Tongzhi	1862–1874
Guangxu	1875–1908
Xuantong	1909–1911

Five Milestones

The First Milestone: Appearance of Pottery in the Early Neolithic Age

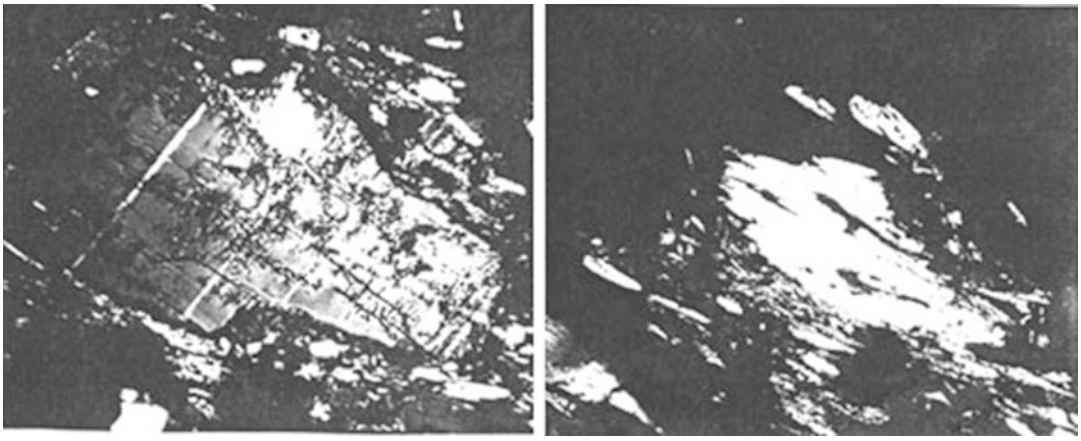
According to archeological information, after the discovery of potteries of the Yangshao culture, the following were discovered:



Ceramics in China, Map 1 Map showing the kilns in different provinces in China (Adopted from Chen, 1990)

- Those of the Hemudu culture in Yuyao, Zhejiang Province about 7,000 years ago
- Those of the Cishan culture and the Peiligang culture about 8,000 years ago
- Those of the Pengtoushan culture in Li County, Hunan Province and the Jiahu culture in Wuyang County, Henan Province about 9,000 years ago
- Those at the Yuchanyan site in Dao County, Hunan Province, the Xianrendong site in Wannian County, Jiangxi Province, and the Nanzhuangtou site in Xushui County, Hebei Province about 10,000 years ago

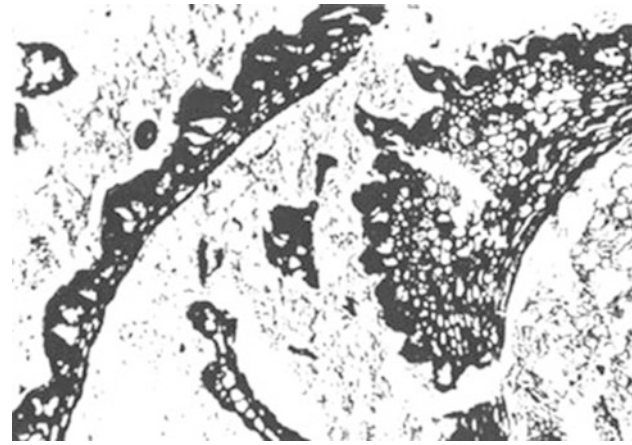
The raw materials for early pottery were all obtained locally. In particular, a common feature for the pottery of about 10,000 years ago is that they were all coarse sandy pottery with coarse and loose textures, so most of them were only small shards when unearthed, and only very few



Ceramics in China, Fig. 1 Microstructure (70×) of sandy pottery from the Nanzhaungtou site in Xushui County, Hebei Province

Ceramics in China, Fig. 2 Microstructure (350×) of sandy pottery from the Xianrendong site in Wannian County, Jiangxi Province

whole pieces could be restored. Their firing temperatures were about 700 °C. For examples, pottery from the Nanzhuangtou site in Xushui County contained big grains of hornblende and vermiculite (Fig. 1), and pottery from the Xianrendong site in Wannian County contained large grains of quartz, dickite, and muscovite (Fig. 2; Li, Xianqiu, Zequn, et al., 1996). This also explained why the pots from the Nanzhuangton site contained more calcium oxide (lime, CaO) and magnesium oxide (MgO), and those from the Xianrendong site contained more silicon dioxide (SiO_2) and potassium oxide (K_2O). In this way, the amounts of calcium oxide and silicon dioxide can be used as characteristic constituents to differentiate between pots manufactured in the northern part and those manufactured in the southern part of China. The microstructure of the black pottery including charcoal from the Hemudu culture was rather peculiar (Li, Xianqiu, Zequn, et al., 1978) and is shown in Fig. 3.



Ceramics in China, Fig. 3 Microstructure (165×) of black pottery including charcoal of the Hemudu culture in Yuyao, Zhejiang Province

Ceramics in China, Fig. 4 Microstructure (140×) of an early proto-porcelain of Western Zhou dynasty from Jiang Shan, Zhejiang Province

The Second Milestone: Successful Firing of Stamped Hard Pottery in the Late Neolithic Age and Appearance of Proto-Porcelain in the Shang-Zhou Dynasty

It is generally accepted that stamped hard pottery first appeared in the late Neolithic age about 4,000 years ago (which could be regarded as the Xia period according to dating results) and that proto-porcelains first appeared in the Shang dynasty. Stamped hard pottery had lower contents of iron oxide (Fe_2O_3) than general potteries. The firing temperature was above 1,000 °C, and the maximum temperature could reach 1,200 °C. Proto-porcelains had even lower iron oxide content; they were in general below 3 %. The highest firing temperature reached 1,280 °C. There were glaze layers of nonuniform thicknesses on the interior as well as the exterior surfaces of proto-porcelains. The glazed layer could be a green glaze with a grayish green or yellowish green color, or a yellow glaze with a greenish yellow or brownish yellow color. Generally speaking, the glaze was not tightly bonded to the body and could be easily delaminated. The glaze contains relatively high contents of calcium oxide, and is thus called *calcium glaze*. This kind of glaze is a unique high-temperature glaze created in China and is the earliest high-temperature glaze in the world (Fig. 4; Li, Xianqiu, Fukan, et al., 1985).

Ceramics in China, Fig. 5 Microstructure (405×) of the glaze of a green-glazed porcelain from the Yue Kiln, Xiaoxiantan, Shangkyu, Zhejiang Province

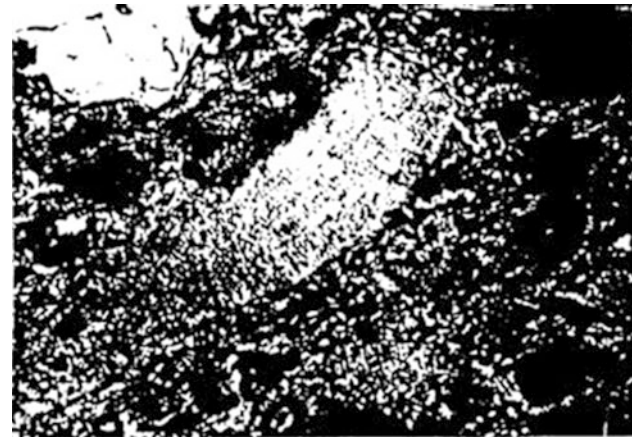
The Third Milestone: Appearance of Green-Glazed Porcelain (Celadon) in Southern China in the Han-Jin Dynasty

The successful firing of the southern green-glaze porcelains, represented by the Yue wares in Zhejiang Province during the late East Han dynasty (AD 25–220), signified another leap in the development of ceramic technique in China. Porcelains first appeared in the world from this period.

Porcelain differed from pottery in that the porcelain appeared to be stronger and more compact. Most were white; some had a grayish tint. Their cross-sections had a glass-phase luster and the thin layer was slightly translucent. They had relatively high contents of silicon dioxide and aluminum oxide (Al_2O_3) and smaller amounts of fluxing agents; they could be fired at higher temperatures and had higher strength. The porosity as well as the water absorption rate was very small. As regards their microstructure, they contained relatively larger amounts of glass phase as well as a certain amount of Mullite crystals. The quartz remnants were small and rounded. The appearance, chemical composition, physical properties, and the microstructure described above are the characteristics of porcelain. Yingxing Song (a famous scientist in the Ming dynasty) describes them as having the "...appearance of white flesh and jade skeleton" in his publication *Tian Gong Kai Wu* (Exploitation of the Works of Nature).

The success of green-glaze porcelains in southern China was primarily attributed to the rich reserve of China stone in the southern part of China. Since at that time only China stone was used as the raw material for porcelain, this led to the early quartz-muscovite series of porcelains with high silicon and low aluminum contents in southern China. The success of green-glaze porcelains could also be attributed to the techniques derived from extensive experience in firing the stamped hard pottery as well as the proto-porcelains.

We use as an example the shard from a green-glazed stamped *Ci Lei* (porcelain drinking vessel) unearthed from the Yue Kiln in Xiaoxiantan, Shangkyu, Zhejiang Province. The iron oxide and the titanium dioxide (TiO_2) contents in its body and glaze are relatively lower, and the titanium dioxide content in the glaze is particularly low. The firing temperature reached 1,300 °C. The body contains relatively larger proportions of the glass-phase. The quartz remnants are small and uniform, while Mullite crystals are ubiquitous. The glaze layer contains extremely small amounts of bubbles and quartz remnants. The glaze layer is a rather thin transparent glass glaze. The anorthite crystallization layer is common at the body-glaze interface, which strengthened the bonding strength of the body and the glaze (Fig. 5). The water absorption rate of the body is only 0.28 %, and the bending strength is as high as 71 MPa. Its chemical



Ceramics in China, Fig. 6 Kaolinite remnant in the body of a white-glazed porcelain of the Xing Kiln (350×)

composition, microstructure, and physical properties perfectly satisfy the requirements for contemporary porcelains (Li et al., 1978).

The Fourth Milestone: Breakthrough of White-Glazed Porcelain in Northern China in the Sui-Tang Dynasty

The breakthrough in white-glazed porcelain in northern China in the Sui-Tang dynasty (AD 589–907) was the result of the rich supplies of high-quality raw materials in northern China as well as experience over a long period of time. Its occurrence was another leap forward in porcelain techniques in China, and made China the first country to possess white-glazed porcelains (Li et al., 1985).

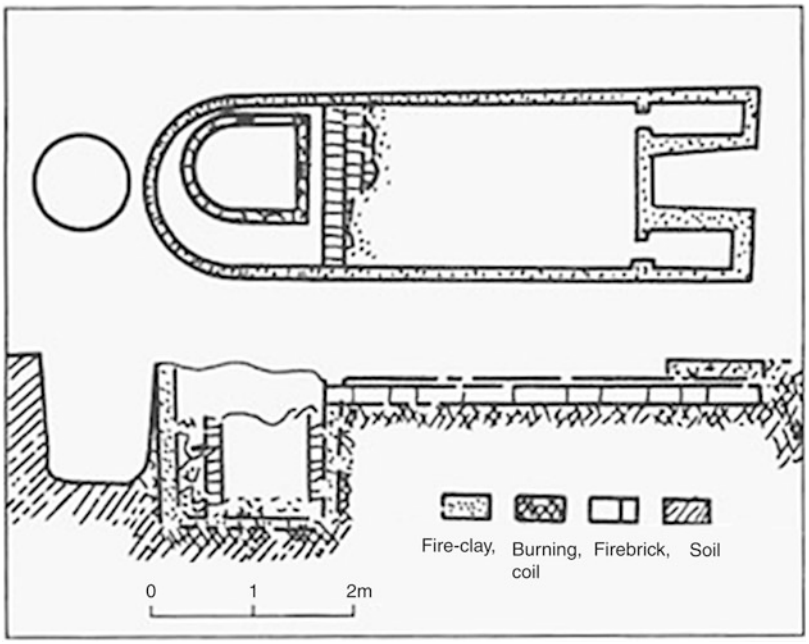
The techniques required by the white-glazed porcelains of Xing, Gong, and Ding Kilns are summarized below.

Use of New Materials and Improvements in the Recipes for the Body and Glaze

All the bodies of white-glazed porcelains of the Xing, Gong, and Ding Kilns made use of secondary settled clay with higher contents of kaolinite or kaolin clay, so their bodies contained more than 30 % of aluminum oxide. Figure 6 shows the microstructure of the body of a white-glazed porcelain of the Xing Kiln, in which a kaolinite remnant can be seen. Furthermore, feldspar was found in the recipes of the body of some white-glazed porcelains, and the potassium oxide content in these bodies could be above 5 %. According to the silicon dioxide contents and α-quartz contents in the microstructure of the bodies, it can be inferred that the kaolin-quartz-feldspar porcelains emerged in the Sui and Tang periods in China. These were not found in the southern green-glazed porcelains. Even when kaolin clay started to be used for the Jingdezhen white-glazed porcelains during the late Song and early Yuan dynasties, these were only kaolin-quartz-muscovite porcelains. These two types of porcelain represented the two major white-glazed porcelain systems in northern and southern China. For some white-glazed porcelains of the Sui dynasty, the potassium oxide content far exceeds that of calcium oxide, the glaze of which is referred to as the alkali-calcium glaze. This is also never seen in the southern early green-glazed porcelains, and only starts to appear in the Jingdezhen sweet white-glazed porcelains during the Yongle period of the Ming dynasty and the Dehua white-glazed porcelains during the Qing dynasty.

Increase in the Firing Temperature and Improvement of the Kilns

The firing temperatures of white-glazed porcelains of the Xing, Gong, and Ding Kilns of the Tang dynasty reached 1,300 °C, and some reached as high as 1,380 °C. The increase of the firing temperature was certainly linked to the improvement of the kilns. The kilns used for the northern white-glazed porcelains in the Sui and Tang periods were up-draught Mantou kilns



Ceramics in China, Fig. 7 Qichun relics of a Xing Kiln in the late Tang period

(Fig. 7). The improvements included big firing chambers, small kiln chambers, and double chimneys, which increased the drag force to enhance the firing temperature.

Use of Saggers and Improvement in Firing Techniques

The firing of Xing Kiln white-glazed porcelains during the late Sui and early Tang dynasties already made use of saggers (a sagger is a case made of fired clay in which porcelain and similar delicate items are enclosed while they are being fired in the kiln) for assembling and firing. The transition from open firing to firing in saggers was a breakthrough to enhance the quality of porcelains. This kiln was one of earliest ones which employed devices for firing in saggers, and possessed various saggers as well as various techniques according to the different forms of porcelains.

The Fifth Milestone: Time of Monochrome-Glazed, Polychrome-Painted, and Sculpted Porcelain from the Song to Qing Dynasty

All the famous porcelains from the Song dynasty to the Qing dynasty (AD 960–1911), such as the imperial wares, Ge wares, Jun wares, Ru wares, Yaozhou wares, Linru wares, Cizhou wares, Jizhou wares, Longquan wares, Jian wares, Changsha wares, Qionglai wares, Dehua wares, Yixing wares, and the later Jingdezhen wares, were all world famous for their monochrome-glazed porcelains, polychrome-painted porcelains, and sculpted porcelains. These porcelains illustrated the great achievements in the sciences, techniques, and arts needed for Chinese porcelains.

Starting from the late East Han dynasty, the Zhejiang Province had been firing celadon with iron oxide as the colorant. Until the South Song dynasty, the black body celadons manufactured in its imperial kiln and the Longquan kiln were crystallization-phase separation-crackle-glaze porcelains. These porcelains made use of the microcrystals of Anorthite and the immiscible liquid droplet separated from the glaze to enhance the jade-like appearance, and exploited the different expansion coefficients of the body and the glaze to generate cracks with different patterns and to become a unique world famous decoration. On the other hand, the white-body celadons were manufactured in the Longquan kiln in large numbers and were

transported to different places in the world and have been collected by all major museums.

The celadons from the Ru Guan kiln and Linru kiln of Baofeng in Henan Province, as well as those of the Yaozhou kiln of Tongchuan in Shaanxi Province, also used iron oxide as the colorant. These porcelains also enjoyed a very good reputation in the world. The celadons from the Ru Guan kiln were particularly precious due to the short manufacturing periods and their small handed-down number.

Black-glazed porcelains emerged almost at the same time as the celadons. All the famous kilns in north and south China manufactured this kind of black-glazed porcelain from time to time, which used iron oxide as the main colorant. With the arrival of the Song dynasty, the techniques in manufacturing black-glazed porcelains had been significantly improved. The most unusual products included the hare's fur bowl of Jianyang, Fujian Province and the black-glazed bowl of Jizhou, Jiangxi Province. These developments were partially attributed to the habit of drinking tea at that time, and partially to the availability of the extremely complicated technology, which was unique in the world. The "hare's fur" was formed by crystallization and then phase separation (or direct phase separation), and then by recrystallization. Under different environments, products with different colors, such as the golden hare's fur and the silver hare's fur, can be formed (Chen, Shiping, Ruifu, et al., 1983a, 1983b). Among these, the fur streaks of some will display different colors in the optical spectrum, which can interchange with each other when observed from different angles. This product is called *Hao Se Bian Yi* bowl (hare's fur bowl with alterable colors), which is a product of the science and technology that integrated the phase separation and crystallization in physical chemistry and thin-film interference or diffraction grating in physical optics. The Hao Se Bian Yi cup transported to Japan was called the *Yohen Temmoku* and was considered a national treasure.

The glaze of the Jun kiln in Yu County, Henan Province was a new product. It was a red glaze colored by copper compounds, or a multicolor glaze with nonuniform red patterns distributed on a bluish opalescent glaze surface with different tints. The blue Jun glaze was not colored by cobalt oxide, but was caused by the stronger scattering of the blue light with a shorter wavelength by the liquid droplet phase which fulfilled the size requirement for Rayleigh scattering. (Rayleigh scattering refers to the scattering of light off of the molecules of the air, and can be extended to scattering from particles up to about a tenth of the wavelength of the light. It is Rayleigh scattering off the molecules of the air which gives us the blue sky.) In other words, this was a kind of physical coloration. The copper-colored liquid phase droplets and cuprite formed the red patches, while the purple streaks were formed by the bluish polycrystals of chalcocite (Chen et al., 1983a, 1983b). The phase separation of the Jun kiln glaze was a physicochemical process taking place within a range of chemical compositions and under the actions of the firing temperature, atmosphere, and time. Because of complicated factors, it was difficult to control the formation conditions, so the appearance of the products could not be controlled easily; this was referred to as furnace transmutation.

Starting from the white-glazed porcelain manufactured in the Five Dynasties to the bluish-white-glazed porcelains in the Song dynasty, Jingdezhen has been one of the greatest kiln sites in terms of quality, quantity, and impact. Before the Yuan dynasty and the early Ming dynasty, there had been ground-breaking developments in the techniques required for Jingdezhen porcelains. The white-glazed porcelains of Shu Fu (Center government in Yuan dynasty) and the sweet white-glazed porcelains of the Yongle period were not only superb in terms of the quality and appearance, but also provided sound techniques and physics foundations for the further manufacturing of monochrome-glazed porcelains and polychrome-painted porcelains. Starting from the Yuan dynasty, Jingdezhen started to fire the blue-and-white underglaze colored by cobalt oxide and the red underglaze colored by copper oxide (CuO), as well as the blue-and-red. This started the manufacture of products with polychrome high-temperature underglazed colorants. In particular, the blue-and-white

porcelains were a unique long-lasting product with the largest sales in Jingdezhen. Furthermore, the different colors created by various metal oxides, such as iron, cobalt, copper, manganese, and their combinations, were the basis for the vibrant color-glazed porcelains from Jingdezhen. At the same time, overglazed painted porcelains started to emerge. When it came to the middle of the Ming dynasty, firing of the so-called *doucai* porcelains was successful, which incorporated the underglazed blue-and-white as well as overglazed paint. The best painted porcelains in the Ming dynasty were the doucai porcelains in the Cheunghua period, which were famous for their vibrant colors, white and moist appearance of the glaze, vivid patterns, and intricate skill work. They were collected in all major museums as well as by private collectors. In the Qing dynasty, there was another type of low-temperature overglazed painted porcelain called *wucai*. These were most famous during the Kangxi period. The subsequent *fencai* porcelains in the Yongzheng period also received great admiration.

After the Ming and Qing dynasties, major kilns all over China perished or stopped manufacturing, except that Jingdezhen kept firing its own colorful porcelains in large quantities and was able to imitate the products from other major kilns. In this way, Jingdezhen became the porcelain center in China and was nicknamed the "Porcelain City."

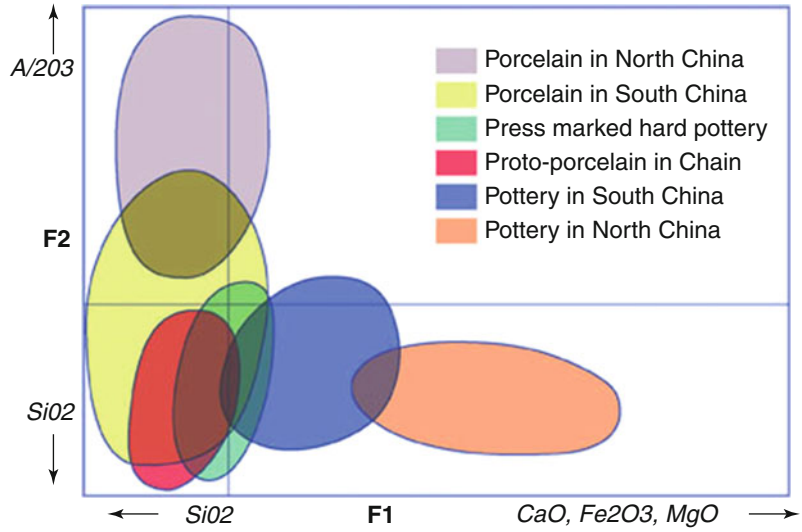
The Dehua kiln in Fujian Province, which was developed some time later than the Jingdezhen, was also world famous for its high-quality white-glazed porcelains and sculpted porcelains. The semitransparent bodies of Dehua white-glazed porcelains, due to the relatively larger proportion of glass and the very thin glaze layer, made the Duhua porcelains uniquely bright.

Before the emergence of the polychrome underglazed painted porcelains in Jingdezhen, the dark brown underglazed painted porcelains colored by iron minerals and those colored by copper materials had already appeared in the Changsha kiln in Hunan Province and the Qionglai kiln in Sichuan Province during the Tang dynasty. These successes had far-reaching influences on the painted porcelains in later generations. When it came to the Song dynasty, the painted porcelains manufactured by all the kilns in the Cizhou ware type in northern China reached another height. Since these were all folk kilns, the portrayed patterns were all derived from the daily lives of the general public, so the patterns had rich flavors of folk lives, which were in great contrast to those of the imperial wares with many more restrictions. These folk wares also created unique decorations which did not exist in the wares from other kilns.

From the proto-porcelains at the second milestone to the monochrome-glazed porcelains, polychrome-painted porcelains, and sculpted porcelains at the fifth milestone, porcelains dominated the history of Chinese ceramics. Interestingly, however, in Yixing, Jiangxu Province, which was also known as the *pottery city*, a world famous pottery called *Zisha pottery* (purple stone ware) has been manufactured since the Song dynasty.

Zisha pottery had many unique features. First, it was especially designed for tea drinkers. The most famous as well as the most manufactured products were teapots with various unique and beautiful forms. Second, it was derived from a unique raw material. The Yixing region is extremely rich in different kinds of Zisha minerals, which were used to produce Zisha pots with different colors. Third, most of the Zisha pottery were handmade, and made use of different tools in the manufacturing process, which fully reflected the wisdom and the skills of the pottery masters. Fourth, the decorations of the Zisha pots were unique in that they integrated the form, painting, poems, calligraphy, and seal cutting, and were thus very rich in Chinese culture characteristics. Starting from the Ming dynasty, there were great masters who made long-lasting famous pots. Therefore, Zisha pottery played a role in the fifth milestone.

When Chinese ceramic techniques developed into the fifth milestone, Chinese ceramics no longer referred to a single region or a particular monochrome-glazed porcelain. Instead, they included the monochrome-glazed porcelains, polychrome-painted porcelains, and sculpted porcelains from different kilns in both southern and northern China.



Ceramics in China, Fig. 8 The scatter plot of the F1 and F2 factors for the chemical composition of the bodies of Chinese ancient ceramics

Three Technological Breakthroughs

The five milestones described above relied on continuous breakthroughs in firing techniques. The latter can be summarized as described below (Li, 1978a, 1978b).

Selection and Refinery of Raw Materials

The raw materials of pottery in general, particularly the early ones, came from the local soil. Therefore, the soil around the residences of early people became the raw materials for firing their pots. Since most of these people resided near hills or close to water sources, the collected raw materials were, in general, soils containing different sand grains. Early pottery was mostly sandy, containing different types of sand grains with different sizes. Strictly speaking, these soils were not suitable for firing pots. After a relatively long period of time, the people became aware that some soils might be more suitable for firing, and they started to select these soils for their pots. In other words, the people started to select the soils locally and clay pottery appeared as a result. When the people discovered that using a particular clay could not satisfy the requirements for forming, drying, and firing, they added different sand grains, ashes of vegetation, and shells of corn, as well as ashes of shells, etc., to get pottery including sand, charcoal, or mussel. The black pottery including charcoal from Hemudu culture was a typical example (Fig. 3).

The raw materials for the stamped hard pottery, proto-porcelains, or even celadons and white-glazed porcelains were still selected locally. However, the people had higher standards for the suitable raw materials. This explained why the stamped hard pottery, proto-porcelains, and celadons were first successfully fired in some regions in southern China, while the white-glazed porcelains were first successfully fired in some regions in northern China. All in all, the raw materials derived from regions which were only suitable for particular types of ceramics.

Differences in raw materials will be reflected by the different chemical compositions of the ceramics. Principal component analyses have been performed on the chemical compositions of the bodies of 700 pieces of ancient ceramics spanning from the Neolithic Age to the Qing dynasty. The cumulative variance explained by the first three principal factors (F1, F2, F3) was more than 80 %. Figure 8 shows the factor loadings of F1 and F2.

From Fig. 8, we can clearly see the changes in the chemical compositions of ceramics in southern China. During the development from the stamped hard pottery to the proto-porcelains and then to porcelains, the silicon dioxide in

Ceramics in China, Table 2 Changes in the firing temperature of ancient ceramics

Product	Sample number	Highest firing temperature (°C)	Average firing temperature (°C)
Pottery	15	1,000	920
Stamped hard pottery	55	1,200	1,080
Proto-porcelain	37	1,280	1,120
Porcelain	146	1,380	1,240

the bodies increased gradually while the fluxing agents calcium oxide, magnesium oxide, and particularly iron oxide decreased. The contents of aluminum oxide did not change much until after the Song dynasty when the aluminum oxide contents increased due to the use of kaolin clay. The chemical compositions of the ceramic bodies had overlaps, which demonstrated their close relationships. However, the ceramics from northern China did not have this pattern. The northern Chinese pottery came from an area with high fluxing agents and low silicon dioxide contents, while the porcelains were in an area with low fluxing agents and high aluminum oxide contents. This is explained by the use of clay which is more readily melted as the raw material for the former and the use of clay with kaolinite as the raw material for the latter. The two regions were well separated, which showed that they had no relationships with each other. The chemical compositions of the small number of stamped hard pottery and proto-porcelain unearthed in northern China did not show any transitional zone between the two regions, so no relationships between their chemical compositions can be inferred. It can be said that the development from pottery to porcelain took a different path in northern China. However, the development from pottery to porcelain together with continuous improvements in their quality was primarily attributed to the selection and refining of raw materials. The raw materials were the fundamental substances for firing the ceramics.

Improvements of Kilns and Increase in Firing Temperatures

According to the vast amount of experimental data obtained for firing temperatures from ancient ceramic shards, it can be concluded that there were two breakthroughs in firing temperature. The first one was realized for the firing of stamped hard pottery in the Shang and Zhou dynasties. The highest firing temperature of 1,000 °C and the average value of 920 °C for pots were increased to 1,200 and 1,080 °C, respectively. The second one was realized for the firing of white-glazed porcelains in northern China in the Sui and Tong dynasties. The highest firing temperature of 1,280 °C and the average value of 1,120 °C for proto-porcelains were increased to 1,380 and 1,240 °C, respectively, for white-glazed porcelains, the latter being the highest firing temperature for porcelains in the history of China. Table 2 summarizes the statistical data for the experimentally determined firing temperatures for pottery and porcelains.

From the archeological data for kilns, we can conclude that pottery from the early Neolithic Age might be fired without kilns, i.e., firing on the ground. Kilns were found from the Jiahu and Peiligang cultures. Kiln firing might have started later in southern China. After a long period of development and improvement, the dragon kiln and the chamber kiln with chimneys appeared during the Shang period in Zhejiang and Jiangxi Provinces. The stamped hard pottery and the proto-porcelain were fired in such kilns. The upward slope and the length of the dragon kilns, as well as the chimney of the chamber kilns, increased the drag force, thus enabling the rise in the firing temperature. This was the first breakthrough in the kiln structure, which facilitated the first breakthrough in raising the firing temperature.

In the Sui and Tang dynasties, big firing chambers, small kiln chambers, and multiple chimneys

appeared in Hebei Province in northern China. As seen from the above, improvements in the kilns were closely related to the increase in firing temperatures.

Invention and Development of Glaze

The earliest glaze which was transparent, bright, and which did not absorb water was the glaze for the proto-porcelains fired in the Shang dynasty more than 3,000 years ago. Therefore, glaze must have been created before the Shang dynasty.

It is well known that the proto-porcelains and the earliest porcelains were fired in southern China. Recently, a large amount of clay-glazed black pottery prior to the Shang period has been discovered in ancient kilns and tombs, and *Tao Yi* (pottery coat) has been discovered on the surface of colored pottery from the early Neolithic era in southern China. The creation and development of glazes in China can be divided into the following four stages, according to their chemical composition, microstructure, and appearance:

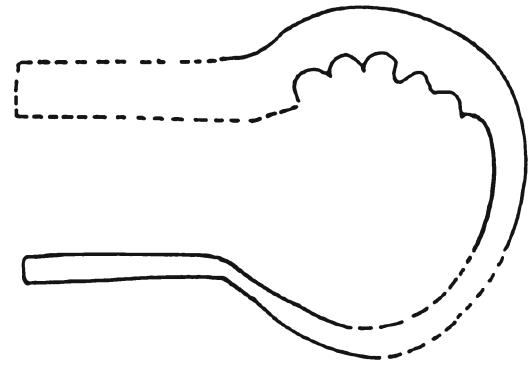
1. Breeding period of glaze – Shang dynasty
2. Formation period of glaze – Shang and Zhou dynasties
3. Mature period of glaze – Han, Jin, Sui, Tang, and Five Dynasties
4. Flourishing period of glaze – from the Song to Qing dynasties (Li, 1983)

Similar to the five milestones, the three technological breakthroughs signified improvements and achievements during the 10,000 years of history from the Neolithic Age to the Qing dynasty.

Contribution to Chinese Culture

Chinese ceramics have a long history, rich technological and arts contents, and are highly acclaimed all over the world. The contribution of ceramics to Chinese culture can be briefly summarized:

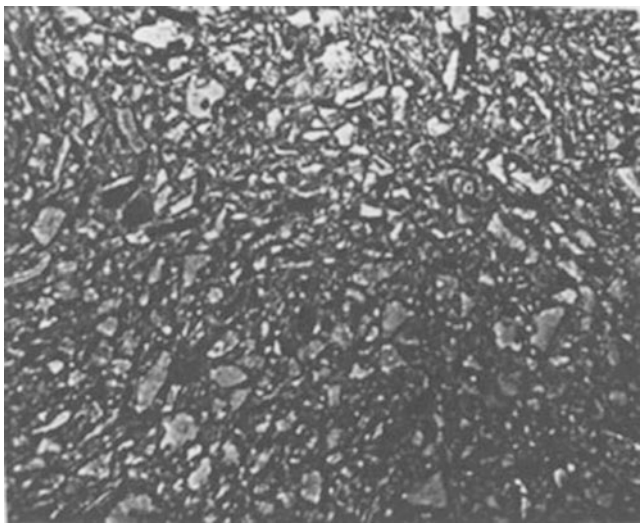
1. The early pottery was based on very simple techniques. Pottery techniques were an integral part of Chinese culture. These techniques were made up by the three stages of raw material selection, forming of the wares and the firing of the pottery. The basic ideas behind the whole set of techniques developed more than 10,000 years ago; they have been used until now, and have laid the foundations of ceramic industries in later generations. With pottery cooking utensils, the people could enjoy cooked food, which enhanced their quality of life. This is important not only for the Chinese culture, but also for world culture.
2. The Chinese culture is one of the four ancient cultures in the world (China, India, Near East, and Greece) that has been sustained until today, with the development of Chinese ceramics as an example of its sustainability.
3. Pottery kilns appeared in the relics of Peiligang in Xinzheng (Fig. 9) and Jiahu in Wuyang in Henan Province about 8,000–9,000 years ago (Kaifeng Managing Committee of Cultural Relics & Xinzheng Managing Committee of Cultural Relics, 1978; Zhang, 1999). These kilns proved that China was one of the first places to fire pottery in kilns. The appearance of kilns enabled the increase in the firing temperature (Table 3). This greatly enhanced the quality of the Peiligang pottery (Fig. 10) and at the same time enabled the first effective step in the history of high-temperature processes for mankind.



Ceramics in China, Fig. 9 Schematic diagram showing the relic pottery kiln T31 in the Peiligang in Xinzheng, Henan Province

Ceramics in China, Table 3 Firing temperatures of some early porcelains from the Neolithic Age

Sample number	Unearthed site and layer	Firing temperature (°C) ±20
1-64WXT $_5$ ④	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (fourth layer)	810
2-62WXT $_3$ ③	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (third layer)	740
12-64WXT $_4$ ②	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (second layer)	800
15-64WXT $_4$ ②		840
6-99WXE $_{10}$N $_{12}$·2A		780
18-64WXT $_6$ ①	Pottery shard from Xianrendong site in the Wannian County, Jiangxi Province (first layer)	800
13-93WXE $_1$ N $_{12}$· 1A		740
	Sandy pottery from Zengpiyan in the Guilin of Guangxi	680
	Sandy pottery from Qingtang in the Yingde of Guangdong	680
EN2	Clay pottery of Peiligang in Xinzheng in the Henan Province	910
EN3	Sandy pottery of Peiligang in Xinzheng in the Henan Province	920
EN4		820



Ceramics in China, Fig. 10 Microstructure of a clay pottery of Peiligang in Xinzheng, Henan Province (70×)

4. Figure 10
5. Table 3
6. Slow wheel trimming for pottery appeared in the middle of the Yangshao culture, 4,000 years ago. Fast wheel trimming occurred during the Dawenkou culture. The fast wheel is also called the *potter's wheel*, which is the rudiment of the jolley (a mold to produce uniform hollow ware) used today. The fast wheel was a necessary requirement to throw as well as trim, and was instrumental in enhancing both the quality and the quantity of the products. The appearance of the fast wheel reflected the use of wheel shaft machines as well as the effects of inertia in manufacturing pottery, which inspired machining processes in later generations.
7. Early pottery contained certain amounts of sand grains with different sizes. Some of these sand grains occurred naturally in soils,

while others were purposely added. The latter ones were referred to as *Chan He Liao*. For example, the burned vegetation found in Hemudu pottery was purposely added (Fig. 3; Li et al., 1978). These additions were used to mitigate the contraction of clay during drying and firing, which served the same purpose as the clinker (a hard brick used as a paving stone) does today.

8. Pottery can be both containers and tools. Earthen spinning wheels, net weights, pills, and casts have been found in many relic sites of the Neolithic Age, which were tools for textiles, fishing, and pottery manufacturing. Despite the very simple forms, these served as the first examples of using pottery as tools, and demonstrated that pottery was an indispensable material in human lives. In particular, the earthen pills and earthen net weights not only signified the exploitation of elastic stress and gravity machines in the manufacturing process, but they also illustrated that pottery needed chemical reactions, which were unlike stone wares which needed only physical processing. This was pioneering in the chemical industry.
9. Pottery was the earliest product integrating technology and arts. Colored pottery was discovered in Jiahu in Wuyang, Henan Province as well as in Hemudu, Yuyao, Zhejiang Province. Colored pottery and pottery statues were also found for the late Neolithic Age. These not only showed the artistic talents of the people, but also reflected their daily lives. For example, carved symbols were found on pottery from the relic site of Jiahu, which provided information on the emergence of Chinese words. Colored pottery was an ancestor to polychrome-painted porcelains in later generations; pottery statues were ancestors to sculpted porcelains.
10. The crucibles for alloy melting for bronze wares and the pottery moulds for casting illustrate the required skills for techniques. The emergence of pottery kilns and the attainment of higher firing temperatures as a result of the improvements in the kilns facilitated the development of bronze wares and thus the early arrival of the bronze-ware era. The early pottery marked the start of the Neolithic Age, but improvements and extended applications played an indispensable role in marking the end of the Neolithic Age and in marking an unacknowledged ceramic Age.
11. Porcelains are recognized as one of the greatest inventions in China. The manufacturing techniques of porcelain masters in different times were adopted by different countries in Europe and Asia, which had significant influence on the manufacture and the development of porcelains in certain countries in the world.
12. One of the main reasons that the Jingdezhen porcelains could survive and their quality improve was that the recipe contains kaolin clay and its percentage kept increasing. The good quality of the white-glazed porcelains from the Xing Kiln in northern China starting from the Tang dynasty was also attributed to kaolin clay. Firing of hard porcelains in Europe was also successful after the use of kaolin clay. China was the first country to discover kaolin clay. The terms *kaolin clay* and *kaolinite* were translated from Chinese.
13. The famous porcelains manufactured in various areas in China not only satisfied the needs of different people in China, but were also exported in large quantities or used as precious gifts. These exquisite porcelains, as part of Chinese culture, were thus dispersed to different areas in the world. This inspired their techniques and at the same time built the reputation of Chinese porcelains over the world.

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Ceramics in Korea

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Korean ceramics is a culture that has been close to the hearts and minds of Korean people throughout its history. In many parts of the country, one can still touch the centuries-old remnants of everyday bowls and dishes and even artistic masterpieces. For those who seek them out by research or consulting with experts and village elders, waste mounds of shards and dragon kilns are invariably found on sunny mountain slopes with flowing brook water nearby. Such artifacts reveal many details of the forming, designing, and firing methods of traditional Korean ceramics.

Today, Korean ceramics is enjoying an active phase of development. For the first time, all four major types of pottery – *togi*, celadon, *punch'ŏng*, and whiteware – are produced simultaneously in numerous studios. With the continued unearthing of kiln sites in major excavations have come new theories about the rise and development of Korean ceramics history. The overseas museum space dedicated to exhibiting ceramic art pieces has increased noticeably in the last decade. Special fairs, biennales, and competitions are held in many locations that attract both Korean and international audiences. The World Ceramic Biennale, held in 2005 for the third time in the greater area of Kwangju (near Seoul; this was the center of ceramic activities during the Chosŏn dynasty), is developing as an important event for ceramic arts and crafts.

Coming of Age for Korean Hard-Paste Porcelain

Among countless types of ceramic products that make ceramic culture ubiquitous, the position held by Korean porcelain and stoneware is due to their hard-paste raw material. Korea and China were the first countries to possess the know-how for using this material, readily available in nature, and obtaining the necessary firing power for its proper vitrification (forming a glassy or noncrystalline material). Although the dates are still being debated actively among ceramics scholars, a long tradition of making high-fired unglazed stoneware, called *togi*, enabled Korea to adopt porcelain technology from China sometime between the early ninth and late tenth centuries. The making of refined teabowls must have been a strong motivation for the import of the technology because shards of such bowls are found in abundance in early kiln sites. The Japanese porcelain industry began only after many Korean potters were taken to Japan during the Hideyoshi Invasion (1592–1598), which is also known as the Ceramics War or the Tea Bowl War.

While China and Japan benefited enormously from the export of their porcelain wares to Europe until the technology successfully developed there in the eighteenth century, Korea maintained its unique aesthetics that were appreciated mainly within East Asia. Never developing the overglaze that was so popular in Europe, Korea produced one major type at a time: *togi*

up to the Unified Silla Kingdom (AD 668–935), celadon during the Koryŏ dynasty (AD 918–1392), and *punch'ŏng* and then more commonly whiteware during the Chosŏn dynasty (AD 1392–1910). Although several other types were also produced – including a substantial amount of white teabowls in the initial stages of porcelain technology, a small amount of black temmoku type, and a very small amount of ware known as Chosŏn celadon with white body and celadon-type glaze – the linear sequential development of the four major types is undeniably the predominant feature of Korean ceramics history.

It is not surprising, therefore, that Korean ceramics remained largely unknown in the world, as attested by Bushell's report in his comprehensive 1896 book *Oriental Ceramic Art*. "Korea has been thoroughly explored during the last few years, and it is now known that no artistic pottery is produced there in the present day, and no indisputable evidence of any original skill in former times has been discovered." Within a decade of this report, an enormous amount of porcelain (including thousands of pieces in many shapes and types) was unearthed during the building of railroads. Many accolades were bestowed on Koryŏ *pisaek* celadon as early as the twelfth century. For example, a Song connoisseur, Taipyŏng Noin, said they were the "First Under Heaven," and a famous calligrapher envoy to Korea, Sŏh Keung, referred to the celadon as being very refined with workmanship surpassing that of the Yüeh kiln (in China). The isolation of Korea from development in other parts of the world resulted in the unique characteristics of simplicity and quietness that today are acclaimed as the quintessence of oriental spirit.

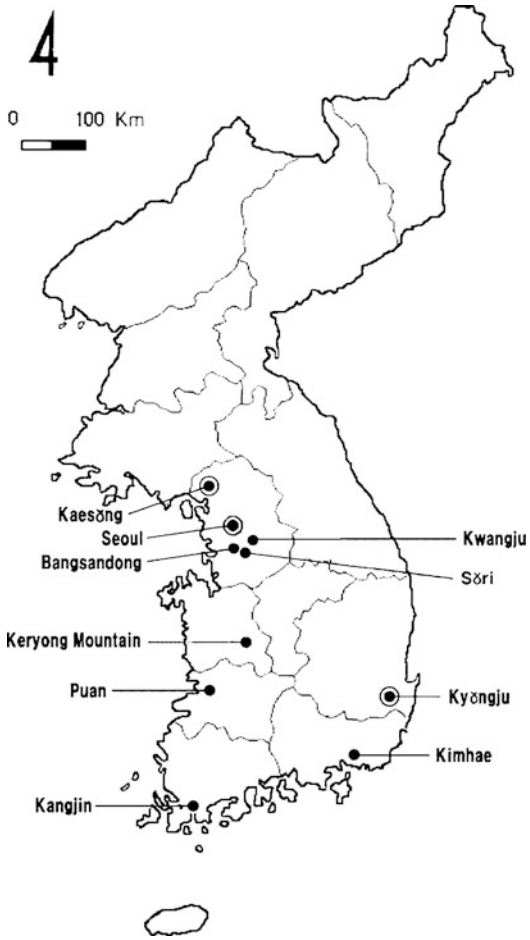
Togi Up to the Unified Silla Kingdom

The term *togi*, with a literal meaning of earthenware or clayware, is used inclusively for a wide variety of mostly unglazed earthenware or stoneware produced from the beginning of the Neolithic Age (ca. 6000–1000 BCE) through the Bronze and Iron ages (ca. 1000–0 BCE), the proto-Three Kingdoms period (ca. AD 0–300),

Ceramics in Korea, Fig. 1 Long-necked jar. Black pottery. Excavated at Kijong-dong. Taejeon. Bronze Age. National Museum of Korea, Seoul

the Three Kingdoms period (ca. AD 300–668; Koguryo in the north, Paekche in the southwest, and Silla in the southeast), and much of the Unified Silla Kingdom. On a much smaller scale, the production of *togi* continued during the Koryŏ and Chosŏn dynasties. One of the oldest Korean ceramic wares known today, a reddish comb-patterned jar with a pointed bottom, is carbon dated to 5770 BCE. Red and black (Fig. 1) pottery from the Bronze and Iron ages attests to the high-level technology and aesthetics that the ceramic culture already obtained. These soft-textured wares were painted with iron pigments and burnished and most likely fired in an open pit.

By the end of the proto-Three Kingdoms period around the fourth century, two breakthroughs allowed the technology to become much more sophisticated and efficient. The potter's wheel was introduced, and the knowledge of high firing power, originally developed for bronze and iron casting, was applied to ceramics production. The type of dragon kilns and the method of reduction firing that Korea used continuously throughout its ceramics history were developed at this date. The *togi* fired in this way was highly vitrified and hard textured to the extent that it rings like porcelain when struck with the fingers. These wares were colored usually blue gray or black gray.



Ceramics in Korea, Fig. 2 Map of Korea with historically important kiln sites and capital cities of different dynasties. Kaesŏng is the capital city of the Koryŏ dynasty (AD 918–1392), Kyŏngju that of the Unified Silla Kingdom (AD 668–935), and Seoul that of the Chosŏn dynasty (AD 1392–1910) as well as modern Korea

The first of these grayish stonewares is known as Kimhae ware after the southeastern area where they were first produced (Fig. 2). Kimhae prospered as an independent state known as Kaya until absorbed into Silla in the sixth century, and the highly vitrified *togi* characteristic of this area is also referred to as Kaya *togi*. Such ware became more refined and was produced in such vast amounts during the Three Kingdoms period and Unified Silla Kingdom that they are found in abundance even today.

The forms of the *togi* bowls and jars already possess the elements of beauty that characterize Korean ceramics in general, especially the slender gracious line of Koryŏ *maepyŏng* and the voluptuous roundness of Chosŏn whiteware jars. Both of these elements make the Kaya pedestalled jars, usually with lids, very attractive. The tall and short pedestals are basic components in much of the *togi* form. Shaped either as part of the whole ware or separately, they often have beautiful contours.

The naturalistic forms of humans, animals and birds, transportation means, and houses were favored motives both as shapes and as decorations. There were many varieties of warriors mounted on horses or carriages (Fig. 3). A roof-end tile, in spite of its monstrous appearance, stimulates the feeling of warmth that is a hallmark of Korean ceramics (Fig. 4). A handsome inkstone is a forerunner of small equipment for calligraphy, which was made both in the Koryŏ and Chosŏn dynasties (Fig. 5). A Silla long-necked jar is decorated with many symbols of fertility and well-being, such as figurines of a snake, a frog, a bird, a duck, a turtle, a woman playing a *kayakum* (a traditional musical instrument), and a man and a woman engaged in a sexual act.

The Unified Silla wares with lead and tricolored glazes of the Tang style are rare examples of low-firing glazes, because they were discontinued in the following Koryŏ dynasty (Figs. 6 and 7). Why Korea stopped this line of development and never adopted or developed the lead-containing materials for overglaze decoration that became so popular and profitable in China and Japan is one of the most interesting questions concerning the Korean ceramics industry.

Some later *togi* wares were glazed, often only partially, but this occurred due to ash falling on them unintentionally in the process of wood firing. Recent excavation of an eight- to ninth-century *togi* site at Kurimni in the southwestern area near the important celadon centers of Kangjin and Haenam offered some circumstantial evidence of glaze being intentionally applied. Such a suggestion is a topic of interest, because it raises the possibility that celadon technology might have arisen indigenously within Korea.

Ceramics in Korea, Fig. 3 Ceremonial vessel in the shape of mounted figures. Excavated at Tomb 127 (the Gold Bell Tomb) in Nodong-dong, Kyŏngju. Three Kingdoms period (Silla). National Museum of Korea, Seoul

Ceramics in Korea, Fig. 4 Round eaves-end tile with goblin-mask design. From Pyŏng-an-do province in northwestern Korea. Three Kingdoms period (Koguryŏ). Diameter 18.1 cm. National Museum of Korea, Seoul

Ceramics in Korea, Fig. 5 Covered ink slab with 13 legs (one is lost). Place of discovery unknown. Three Kingdoms period (Paekche). National Museum of Korea, Seoul

Celadon in the Koryŏ Dynasty

The appreciation of Korean ceramic art usually begins with numerous celadon masterpieces in the shape of *maepyŏng* vases, which inherited from the *togi* tradition the graceful elegant contours of the pedestalled jars and other vessels. This type developed widely and artistically with many variations in the shape and styles of decoration. The earlier ones decorated with only incised designs are often *pisaek* and beautiful. Many were decorated with inlaid designs of clouds and cranes (Fig. 8), and some rare pieces were painted with iron-black slip before the glazing (Fig. 9). The gourd-shaped ewer with decoration of copper red is a variation in shape (Fig. 10).

The love of naturalistic forms of plants, animals, and birds was also inherited from the *togi* tradition. Notable among them are many water droppers, such as a child holding a bottle and a monkey holding a jar as big as itself (Fig. 11). An ewer in the shape of a dragon-headed tortoise seated on a lotus pedestal (Fig. 12) and an incense burner with the lid and feet in the form of lion figures (Fig. 13) are some of the celadon vessels with elaborate naturalistic forms.

Another form that was dominant in the Koryŏ dynasty was the teabowl (Fig. 14), as the act of drinking tea was a highly valued means to clear one's mind for meditation in the Buddhist Koryŏ dynasty. The teabowl shards excavated in the

Ceramics in Korea, Fig. 6 Green-glazed covered bowl containing six small covered bowls (cinerary urn). From Kyŏngju area. Middle Unified Silla period. National Museum of Korea, Kyŏngju

Ceramics in Korea, Fig. 7 Covered bowl with three-color glaze (cinerary urn). From Kyŏngju area. Middle Unified Silla period. National Museum of Korea, Seoul

earliest porcelain kiln sites have a particular style of wide foot rim that resembles the sun's halo and is called, in Korean, *haemurigup*. The similarity in these foot rim styles, glaze colors, and general shapes of these wares with those found in Yüeh kiln is one of the reasons to believe that the Korean porcelain technology was strongly influenced by the Chinese technology or even that it was directly imported from China (Fig. 15).

Ceramics in Korea, Fig. 8 Celadon *maepyŏng* with inlaid decoration of cloud and crane. Twelfth century. Height 30 cm. Provenance unknown. National Museum of Korea, Seoul

Ceramics in Korea, Fig. 9 Celadon-glazed iron-black *maepyŏng* decorated with floral design in white slip. Mid-twelfth century. Height 27.5 cm. National Museum of Korea, Seoul

Haemurigup teabowls in recent excavations included surprisingly both celadon and whiteware. In particular, a series of excavations in Sŏri and Bangsandong in the 1980s and 1990s near Seoul showed that whiteware was just as important as celadon in the earliest stages of

Ceramics in Korea, Fig. 10 Gourd-shaped celadon ewer with stopper and bowl, decorated with overall inlaid design of boys among grapevines. The grapes are painted in underglaze copper red. Second half of the twelfth century. Height 36.1 cm. National Museum of Korea, Seoul

Ceramics in Korea, Fig. 11 Celadon water dropper in the shape of a monkey holding a jar. The eyes are marked with iron spots and the hairy body is executed with incised lines. First half of the twelfth century. Height 7.2 cm. National Museum of Korea, Seoul

porcelain technology in Korea. During the latter part of its two-century-long production, Sŏri produced only whiteware, and another nearby site of Chungamni also produced mainly whiteware during its entire existence.

Ceramics in Korea, Fig. 12 Celadon ewer in the shape of a dragon-headed tortoise seated on a lotus pedestal. The head, body, and twisted lotus-stem handle are modeled. First half of the twelfth century. Height 17.0 cm. National Museum of Korea, Seoul

Ceramics in Korea, Fig. 13 Celadon incense burner with cover. The vessel has three lion-headed feet and decorated exterior with incised clouds. First half of the twelfth century. Height 17.5 cm. National Museum of Korea, Seoul

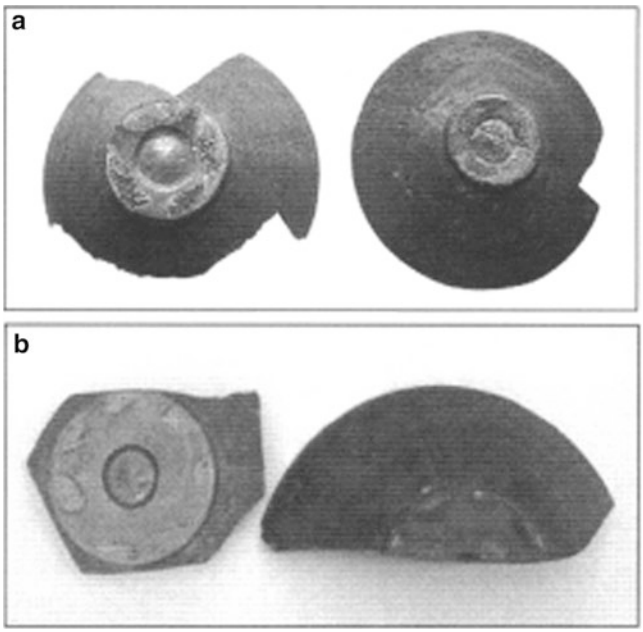
Sŏri, Bangsandong and Chungamni were among some 50 sites located inland in the western midsection of the country, and they are now considered one of two distinct routes of technology transfer from China. The other route consists of a group of sites in the Kangjin area on the southwestern coast. These two different routes show several remarkable differences. Unlike in

the inland kiln sites, only celadon is found in Kangjin. From the beginning, Kangjin kilns were constructed with mud and rock in a similar style to *togi* kilns, while kilns in inland sites were first constructed with bricks as in some Chinese kilns. Only later was the Kangjin-type kiln of mud and rock introduced to some of the longer running inland sites such as Sŏri. Kangjin fired the wares in two steps – once before and again after glazing – while inland kilns fired wares in one step like the Chinese.

Ceramics in Korea, Fig. 14 Celadon bowl with inlay decoration. Mid-twelfth century. Height 6.4 cm. National Museum of Korea, Seoul

By the middle of the eleventh century, the inland kilns were mostly closed, while another center at Puan about 200 km north of Kangjin was newly established. The founding of Puan and closing of the inland kilns represented a new and indigenous phase of porcelain technology. In the two centers of Kangjin and Puan on the southwestern shore, porcelain production became highly centralized and reached a high technical and aesthetic level. Dedicating their efforts only to celadon rather than producing several styles, Koryŏ potters and their patrons made three original achievements in ceramic arts and crafts: *pisaek* glaze, the decorative technique of white and black inlay, and that of copper red.

Pisaek, represented by two different Chinese characters, mainly appears in a jade color and kingfisher's color (after the bird's blue-green plumage) in Korea and as a secret color in China. In the Koryŏ *pisaek* celadon, the thin glaze blends with the body of the ware, revealing it just enough that the observer yearns to see more. Chung Yangmo, a leading historian of ceramic arts and former director of the Korean National Museum, likened the Korean celadon glaze to clear water flowing through



Ceramics in Korea, Fig. 15 (**a**) Whiteware shards with *haemurigup* foot rim, excavated in Sŏri, Korea. (**b**) Celadon shards with *haemurigup* foot rim, excavated in Yüeh, China

brooks and streams in the mountains and valleys and to a partition screen made of ramie fabric.

The thin transparent glaze that showed off the celadon body in a harmonious way was ideal for underglaze decorative techniques. Perhaps such a success enabled and motivated Koryŏ and later Chosŏn potters to persist with only underglaze decorations. The first decorative effect was achieved simply by incising figures such as flowers and birds or making them stand out in relief. The second of the three achievements was made when the incised lines were filled with white or red (which turns into black when fired) clay material to contrast with the gray body color. Flying cranes among stylized clouds (Fig. 8), ducks playing underneath plants such as willow trees and reeds, and various renditions of lotus, chrysanthemum, and peony flowers are some of the inlaid designs.

The third original achievement was the use of copper red, and this represented a technical challenge that required a good control of firing atmosphere and schedule. The volatile copper turns green when oxidized to its divalent state of cupric oxide (CuO). By the first half of the twelfth century, the subdued red from the reduced state of cuprous oxide (Cu_2O) and copper metal in colloidal state was used only sparingly in most cases to represent grapes (Fig. 10) and peony sprays (Fig. 16). It was used to outline lotus petals in gourd-shaped ewers and to cover the entire ware (Fig. 17).

Though the predominant wares were glazed gray green or blue green similar to *pisaek* celadon, some unusual glaze and decorative methods were produced. The entire body of *maepyŏng* (Fig. 9) is first coated with black pigment and decorated by brush painting with white slip before a clear glaze is applied. Another type is colored light brown, most likely to have been fired in an oxidizing atmosphere. Often it is brush painted with iron pigments and resembles Cizhou wares. Even a small amount of porcelain whiteware, in general much more vitrified than the whiteware teabowls of the earliest stage, was produced at Puan (Fig. 18).

Ceramics in Korea, Fig. 16 Celadon *maepyŏng*, decorated with black and white inlaid peony sprays and chrysanthemum scrolls and underglaze copper red. Mid-twelfth century. Height 34.6 cm. National Museum of Korea, Seoul

Ceramics in Korea, Fig. 17 Celadon cup and stand, decorated entirely in underglaze copper red. First half of the twelfth century. Height 6.7 cm. National Museum of Korea, Seoul

Punch'ŏng and Whiteware in the Chosŏn Dynasty

Punch'ŏng grew directly out of inlaid celadon in the last decades of the Koryŏ dynasty when the government became too weak to keep the ceramic activities supervised and centralized. In the first two centuries of the Chosŏn dynasty, *punch'ŏng* blossomed into a folk craft and art

Ceramics in Korea, Fig. 18 White porcelain *maepyŏng*, decorated with black and white inlaid floral designs. Mid-twelfth century. Likely to have been made in Puan. Height 28.8 cm. National Museum of Korea, Seoul

Ceramics in Korea, Fig. 19 *Punch'ŏng* jar with lid. Arabesque design painted in underglaze iron. Sixteenth century. Height 17.2 cm. National Museum of Korea, Seoul

that was unique to Korea. Some of the earliest pieces are difficult to differentiate from heavily inlaid celadon. The white slip material was eventually coated or brushed over the entire body surface before any further decoration was applied (Fig. 19). The name *punch'ŏng* was coined for this type of ware by Koh Yusŏp, a scholar of Korean ceramics in the first decades of the twentieth century, and was adapted from the longer term, *punch'ŏng* (powder-decorated) *whe-ch'ŏng* (gray-blue) *sagi* (stoneware). The white slip was first used as a decorative medium easier to apply than white inlay, but eventually it became a means to make the wares appear whiter to meet the demand of royalty and officials who favored heavily the whiteware. The production of *punch'ŏng* came to an abrupt end after the Ceramics War. With so many potters taken to Japan, only the whiteware production was revived afterward in Korea.

Punch'ŏng is vigorous in form and decoration modes. Unlike celadon, it was produced in all parts of the country, and different styles reflected the people's daily lives, rooted deeply in the earth and other natural environments. The free-spirited spontaneous flow manifested in *punch'ŏng* led Koh Yusŏp to characterize Korean ceramics as made with "a plan without planning" and "technique without technicalities."

Celadon inlaying techniques became modified in many ways. The incision of designs was replaced by stamping with engraving tools or even with rope. Instead of filling individual incised lines or surfaces with inlay material, white slip was applied on the whole stamped body. When the body and the slip were leather dried, the surface was scraped off evenly with the stamped areas left with white inlay. In another modified method, all the areas except those of such designs as flowers and plants were scraped off. Sometimes the scraped background was painted with iron-rich clay to contrast with the decorative area.

In more casually made wares, the only decorative element was white slip that was applied freely and unevenly with a large coarse brush. The abstraction of designs is bolder and more freely executed when they are brush painted with iron-rich pigment over white slip (Fig. 19). Those made in such styles in the area of Keryŏng Mountain became particularly popular with the Japanese.

Together with *punch'ŏng*, white porcelain replaced celadon as the dominant type in the Chosŏn dynasty. Chosŏn potters were able to produce much more vitrified whiteware than Koryŏ counterparts by adopting the two-step

firing method that Kangjin and Puan had developed and used throughout their celadon production history. The adoption of Confucianism and its stern frugality from the Ming dynasty as the guiding principle of the new society to replace the Koryŏ lifestyle of pleasure and luxury provided the crucial force for the ascent of the whiteware technology. The undecorated pure white was preferred, and the decoration was again limited to underglazing. The import of cobalt blue from China to produce white and blue represented the only innovative element in the new Chosŏn technology.

The raw material for Chosŏn whiteware was rediscovered in the area nearby Sŏri and Bangsandong, two centers where Koryŏ whitewares were produced at the beginning stage of porcelain technology centuries earlier. Except for the lower contents of iron and titanium oxide, it is basically the same porcelain stone that is used for celadon. This general area with plentiful raw material, Kwangju near the ruling center in Seoul, was soon established as the official kiln for producing high-quality wares for the use at court. In much the same way as in Kangjin and Puan, the ceramic activity in Kwangju was supervised and centralized by court officials for nearly 500 years. So far some 285 sites have been discovered in this area, where the potters had to move to new sites approximately every 10 years in search of firing wood. Unlike celadon, the production of whiteware, however, was not restricted to this area and was produced all over the country.

The majority of Chosŏn whiteware was undecorated. As mentioned before, the colorful overglaze decoration was never developed, and even the underglaze decoration with cobalt, iron, and copper oxides was sparingly used. However, the various shades of white for body and transparent glaze, combined with beautiful forms, resulted in some of the most appreciated masterpieces. The eighteenth-century jar with globular body is representative of such pure white, imparting the feeling of abundance and warmth (Fig. 20). This particular form is made in diverse modifications and decorated with various designs and colors. The brush painting with cobalt blue

Ceramics in Korea, Fig. 20 White porcelain jar with everted lip and globular body. Late seventeenth century. Height 40.8 cm, National Museum of Korea, Seoul

Ceramics in Korea, Fig. 21 Blue and white jar with cloud and dragon design. Second half of the seventh century to early eighteenth century. Height 35.3 cm. National Museum of Korea, Seoul

on a late seventeenth-century or early eighteenth-century globular jar is executed freely and boldly in the same characteristic manner as *punch'ŏng* wares (Fig. 21).

The cobalt blue decorated wares, made mostly for royal use, are usually refined and restrained. The cobalt pigment, imported and expensive, was usually used sparingly (Fig. 22). When its use became even more difficult after the war with Japan, iron pigment was substituted as the main pigment. It was used more freely and effectively in various styles of brush painting, some refined and some very daring (Fig. 23). The use of copper red, which became more liberal in the eighteenth and nineteenth centuries, produced various styles of jars, bottles, and water droppers that are very

Ceramics in Korea, Fig. 22 Blue and white porcelain angular bottle with orchid design. Second half of the seventeenth century. Height 41.5 cm. National Museum of Korea, Seoul

Ceramics in Korea, Fig. 23 White porcelain bottle coated with underglaze iron. Second half of the eighteenth century. Height 27 cm. National Museum of Korea, Seoul

free spirited (Fig. 24). In some rare pieces, two of the three pigments are used in combination, and very rarely all three pigments are used, always very sparingly.

Ceramics in Korea, Fig. 24 White porcelain water dropper coated with underglaze copper red with molded double crane design. Nineteenth century. Height 5.4 cm. National Museum of Korea, Seoul

This short treatment of 8,000 years of Korean ceramic art and culture, linearly developing *togi*-celadon-*punch'ŏng*-whiteware as distinct phases of creative and original achievements, leaves many important stories untold. Many teabowls of the Koryŏ and Chosŏn dynasty that became national treasures in Japan and the brown pottery known as *onggi*, which ranges from small boilers for herbal medicines to enormously large storage jars, are important examples that have been omitted altogether. The masterpieces and coarse everyday utensils are testimony not only to the availability of diverse materials and technical know-how of Korean potters and their clients but also their creative spirits, their love of nature, and their dreams and ideals.

Scientific Study on Traditional Korean Ceramics

Within Korea the scientific study of Korean traditional porcelain began about 25 years ago in the late 1980s. The first such work was presented internationally in 1992 in the Proceedings of Material Science Society of America. Chinese ceramics had been an academic subject of scientific investigation and analysis for almost a century in several western countries such as Sweden, England, and America and eventually in China itself. Some of the important results culminated in the first proceedings of the international

symposium in 1982 organized by the Shanghai Institute of Ceramics and several volumes of *Ceramics and Civilization*, edited by MIT's W. D. Kingery. Serious analytical works abroad on Korea began in the 1980s by scientists like Pamela Vandiver and Richard Newman in America, Nigel Wood in England, and K. Hangst in Germany.

One of the preparatory aspects of the Korean study was to locate the waste mounds of shards, kiln equipment, and clumps of fired clay left at the original production sites. It was not easy to find them any more, as the kiln sites were erased out of existence to make room for cultivating fields, houses, roads, and dams. After endless inquiries in books and to village elders, one still can be lucky to find them tucked away quietly, along mountain edges with water streams flowing nearby. The spots are invariably sunny and beautiful like the ones that must have been sought after ardently to bury loved ones, as graves are often found close by. The shards chosen as representative ones in such sites were the first ones to be analyzed in the initial stage when various experimental methods were tested and established for the new study.

Soon the community of ceramic historians and archaeologists joined the effort to understand Korea's ceramic heritage from scientific and technological points of view. Well-documented shards from systematic excavations and surface investigations by leading museums and ceramic studio institutes were donated, enabling the analysis work to become systematic with the possibility to connect the results with artistic functional features. For this reason archaeological information and visual features of the shards were recorded meticulously before they were analyzed for their compositional and microstructural characteristics.

The work was initially led and centered at a laboratory in the Department of Scientific Studies of Cultural Heritage in Chung-Ang University but quickly spread to several other centers. Eventually more than 1,500 shards of celadon, punch'ŏng, and whiteware were collected and studied in Chung-Ang University alone, where they are organized by ceramic types, locations, and periods of their production and stored for further studies. From these studies were worked out the developmental changes of the ceramics from celadon to punch'ŏng, and to whiteware, and these were presented in a series of three papers in English in a Korean journal named *Journal of Conservation Science*.

Body Composition

Regardless of the ceramic types, a predominant proportion of the Korean bodies was formed with a hard-paste clay material called pottery stone or porcelain stone. Such is the case in southern China, too. This material is an intermediary type of clay formed during the disintegration process from igneous rocks of feldspar into kaolinite. In the process, the alkali oxides of Na_2O and K_2O from feldspars are leached out until pure kaolinite ($Al_2Si_2O_5(OH)_4$) is formed. Feldspars do not have plasticity to be formed into bodies, and plastic kaolinite is so highly refractory that it requires an extremely high firing power to vitrify. However, porcelain stone in the mid-stages contains various minerals in a wide range of concentrations in such a way that they can be used as they are found with only the physical processes of powdering and purification.

In the process of transformation, hydromical clay is formed in such mineral forms as muscovite, illite, and sericite, and even a small amount of primary kaolinite. Hydromical clays are plastic due to the mineral structure of their sheets in a similar fashion to mica; they also have fluxing property from the alkali oxides still retained in them. In addition to the newly formed clays, porcelain stone from the intermediary stages contains the remnant feldspar and the original quartz. These various minerals make the porcelain stone become triaxial, as they contain all three different properties to form and vitrify ceramic bodies. The plasticity of hydromical clays and a small amount of kaolinite allows the clays to be formed into various shapes, the fluxing property of hydromical clays and feldspars makes the bodies to be vitrified, and the refractory quartz retains shapes as the bodies are fired and become molten at high temperatures. Porcelain stone from earlier stages is sometimes referred to as glaze stone

because higher amount of feldspar still retained makes the material have a higher fluxing property and thus make it appropriate as the flux component in making glaze batches. Often glaze stone is found finer grained than porcelain stone.

The porcelain stone and glaze stone are found in abundance in Korea as in southern China. There is a geological dividing line called Nan Shan Quiling that runs in a west–east direction roughly midway between the Yellow River and Yangtze River in China. This line extends up northeast to Korea, and south of this line porcelain stone is found in abundance; in the north there is kaolinite. Therefore, the majority of Korean and southern Chinese wares from such kilns as Yüeh kiln, Jingdezhen, and Dehua are made with porcelain stone. On the other hand, the northern wares from such kilns as Yaozhou, Ding, and Linru are formed with kaolinite and fired at higher temperature around and above 1,300 °C.

Among the Korean ceramic bodies so far analyzed, only shards that may have been formed from kaolinite are the late fifteenth-century whiteware shards from local kilns of Chunghyodong and Yonggye-ri in Jeolla South Province. Chunghyo-dong had been successfully producing punch'ŏng for half a century before attempting to make whitewares in around the 1450s. Their first whiteware was soft textured, because their firing power was far too low to vitrify the bodies formed of kaolinite clay. Only about 20 years later, it succeeded in vitrifying properly because they added to the kaolinite some glaze stones particularly rich in albite, Na_2O-based feldspar. Adding glaze stone to bring down the firing temperature of kaolinite bodies had occurred more than a century earlier at Jingdezhen in China during Yuan dynasty (1279–1368), but such a practice was not common in the fifteenth century. At present nothing is known about how Chunghyo-dong potters were inspired to use such an innovative material or whether such material was used significantly in whiteware kilns of later times. To date only a limited number of later kilns in rural areas have been excavated, and eighteenth- and nineteenth-century kilns have been excluded from the collection of 1,500 shards so far analyzed at Chung-Ang University.

The porcelain stones appropriate for different ceramic types contain different levels of iron oxide and titanium oxide. Ideally the material for whiteware should contain as little of Fe_2O_3 as possible, and in Chinese its level was mostly less than 0.5 wt%. Unfortunately, Korea lacked such pure material, and in some whiteware shards, as high as 2 wt% level was often found. In general its level in whiteware ranged between 1 and 2 wt%, in celadon between 2 and 3, and in punch'ŏng between 2.5 and 4. In the similar way, the level of TiO_2 should be nearly zero for whiteware, but in Korean whiteware as much as 0.4 wt% has been found. In celadon and in punch'ŏng, the presence of certain amount is needed to make the body fire to gray, and its level was found in the range between 0.5 and 1.0 wt%.

Glaze Composition

Traditional Korean glazes are high-fired glazes formulated by mixing two different types of material, clay and flux component, as was the case with the majority of southern Chinese kilns. Within this system of two components, changes occurred over Koryŏ celadon and Chosŏn whiteware glazes. Although certain punch'ŏng kilns initiated change that eventually became established as normal whiteware practice, punch'ŏng wares kept many of the celadon practices well into the newly found Chosŏn dynasty.

Calcium oxide was the chief flux ingredient in all but a few cases, and it was provided in the form of wood ash, burnt limestone, or powdered limestone. The level of phosphorus oxide P_2O_5 in the glaze composition is a good indicator whether and how much wood was involved in the preparation of the flux material. Wood ash was the earliest traditional flux material, and in some Korean porcelain, it is likely to have been added by itself to the clay component. In an extensive compositional analysis study, Sŏri is found to have been such a center. Both celadon and whiteware glazes from Sŏri complex contained P_2O_5 in high levels above 1.5 wt%.

In the majority of Koryŏ glazes, however, P_2O_5 is found in a concentration range between 0.5 and 1.0 wt%. Meanwhile, CaO is found in a high concentration range between 15 and 22 wt%. Such a small ratio of P_2O_5 and CaO implies that burnt limestone and not wood ash was employed as the main flux material. Known as glaze ash, the burnt limestone was an ideal flux material especially for the high-lime glazes with limited level of phosphorus, which were used persistently at Kangjin and Puan, the centers of inlaid celadons. High-lime glaze becomes transparent when fired to high temperature and cooled rapidly, and a moderate amount of bubble created by limited level of P_2O_5 in glaze ash makes the glaze become somewhat translucent. Such glaze shows off the underglaze decorations of incised and inlaid designs quite clearly and at the same time softens the images. The centers of the inlaid celadon of Kangjin and Puan used this high-lime glaze with a limited level of P_2O_5 persistently. Sometimes burnt shells may have been used, too, as they are found easily in these complexes in southwestern coastal areas.

In many cases of celadon, burnt limestone may have been supplemented with wood ash. *punch'ŏng* wares produced from the last decades of the Koryŏ dynasty in fourteenth century until the early decades of the sixteenth century in Chosŏn dynasty continued to employ celadon methods of obtaining flux material by burning wood by itself for wood ash or burning limestone to make glaze ash. However, in making whitewares at the royal complex in Kwangju, such a practice of using wood disappeared, only with a few exceptions of the early fifteenth-century kilns, where a special ceramic type known as Chosŏn celadon was made as one of their regular productions. These wares were made of whiteware bodies but had celadon glazes, whose flux continued to use the celadon tradition of using wood in some capacity. A low level of P_2O_5 around 0.2 wt% was detected in their whitewares, but in kilns of the late fifteenth and early sixteenth centuries, it is no longer detected. By such time the important change of using limestone in its powdered form had occurred.

Another important change accompanied the change to a powdered form of limestone. Less flux was used, making the concentration of CaO decrease to about 15–10 wt% from the range of 15 to 20 in celadon. Instead the concentration of alkali oxides, Na_2O and K_2O, increased. In the scheme of categorizing high-fired glaze types according to the concentration of CaO and alkali oxides into four types of high lime, lime, lime alkali, and acid rock, the Kwangju whiteware glazes ranged between lime and lime alkali, changing from celadon glazes that ranged between high lime and lime. The latest kiln sites of official Kwangju complex Geumsa-ri and Punwŏn Village of the eighteenth and nineteenth centuries where blue and white were produced increasingly in greater quantity used the lime-alkali type. This type had become the favored one at Jingdezhen in China, too, as it is rather viscous and does not diffuse the cobalt decorations as much as glazes with a higher amount of calcium oxide. Geumsa-ri complex is acclaimed for having produced some of the most beautiful whiteware, especially those with snow-white or milk-white glazes. The fine quality of its glaze composition may be in some way due to an unusually high level of MgO around 4 wt%, more than double the usual amount.

As for the clay component in glaze formulation, often slightly different forms of clay like glaze stone instead of the clay used for the body itself was employed. The relative levels of titanium oxide in the glaze and body have been a good guide to decide which. In Yüeh kiln, one of the most influential Chinese kilns to Korean ceramic technology, the TiO_2 content in the glaze was found to be usually about 80 % of that in the body. Such a compositional characteristic resulted from the practice of mixing body clay with flux material in proportions around 8:2. Such a consistent proportional relationship was not found in Korean glazes. In Bangsandong and Sŏri kiln sites, its level in whiteware glaze was slightly higher than that in the body. A similar situation was observed for iron oxide Fe_2O_3. On the other hand, in Kangjin complexes the level of TiO_2 in the glaze was only about one third of the level in the body.

Clearly such levels of TiO_2 content in Korean glazes could not have been obtained by using the body material itself. It is logical that glaze stone was used in Korean glazes, because it has the same characteristics as porcelain stone, except it has more alkali oxide content and is in general finer grained. What is surprising is that it was employed from the very beginning stages of Korean porcelain, as practiced in the earliest kiln complexes as Bangsandong, Sŏri, and Yongun-ni of Kangjin.

Glaze stone is a versatile material with a wide range of composition, which would depend upon various factors such as the composition of the original mother rock and the particular stage of transformation when it is found. A wide compositional range enabled potters to search for and choose a batch of glaze stone appropriate for their particular wares. There is also a possibility that glaze stone was used together with the body material of porcelain stone in order to bring about the desired effect that the potters were looking for. For their whitewares, Bangsandong and Sŏri potters had to find glaze stone that was almost free of TiO_2 and Fe_2O_3 except in the smallest concentrations of a few tenth of a weight percent. For their celadon glazes, Kangjin potters needed glaze stone with the TiO_2 content around 0.4–0.5 wt%, about half of the level found in celadon body material. Fortunately, such ceramic materials with similar compositional characteristics were available rather easily at close distances, as the Kangjin area had not only an abundance of celadon materials but also mines of porcelain and glaze stone with such low TiO_2 content that they could well have been used to make whitewares. Actually such a mine exists to this day in front of Jŏngsusa, a temple that used to be the spiritual center of celadon potters.

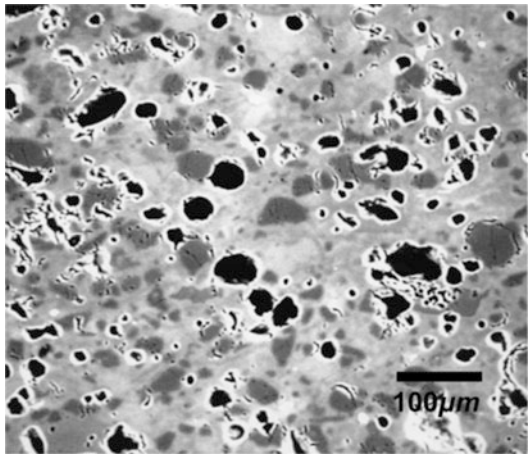
When the new Chosŏn dynasty began, glaze stone as free of TiO_2 and also of Fe_2O_3 as possible was adopted both for whiteware and punch'ŏng. Such a selection is expected for whiteware, but it is quite surprising that even punch'ŏng glazes followed the same change while keeping other characteristics similar to those of celadon. The range of Seger values of SiO_2 and Al_2O_3 and also the levels of P_2O_5 and CaO contents in punch'ŏng were similar to those of celadon. The practice of burning limestone and using it as a flux component by itself or in combination with wood ash lasted much longer in making punch'ŏng glazes than in making whiteware glazes, for which limestone was soon powdered.

Another characteristic of the glaze stone adopted for the lime and lime-alkali glazes of the Chosŏn dynasty is its increased content of alkali oxide. Such glaze stone is an earlier product in the process of transformation from the original feldspar state into the final kaolinite state. A pronounced form of early product rich in feldspar content, especially albite, was used at Chunghyo-dong in the middle of the fifteenth century in developing a glaze with a composition close to acid rock. The combined content of Na_2O and K_2O was higher (8.42 wt%) than the content of CaO (7.01 wt%). Such a unique glaze composition was not observed anywhere else in Korea until then, and only at another contemporary kiln nearby at Yonggye-ri. As with the case of innovative Chunghyo-dong bodies, whether such a new type of glaze was used significantly in later kilns is not known at the present time, since eighteenth- and nineteenth-century kilns in rural areas away from Kwangju system are not included in the scientific study.

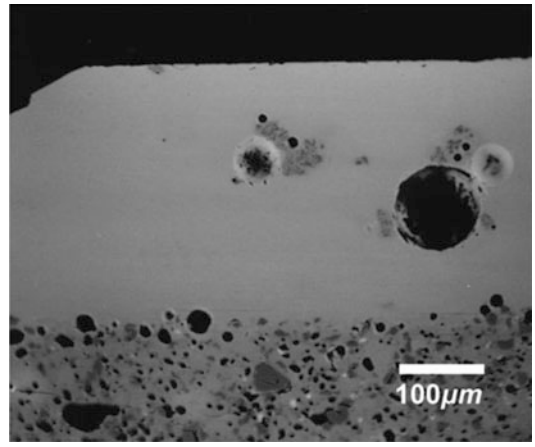
Science of *Pisaek* Celadon

The production parameters of Koryŏ celadon were lost to modern Korea, and the revival of its art and craft in the latter half of the twentieth century was carried out much in trial-and-error efforts. A systematic analysis study dedicated to bisaek celadon is yet to take place, and its compositional and microstructural characteristics are only understood in general terms worked out for celadon. The bodies of celadon considered bisaek appear to be much whiter than common celadon gray bodies, so that their contents of Fe_2O_3 and TiO_2 are suspected to be lower. However, such a systematic difference has not been yet established.

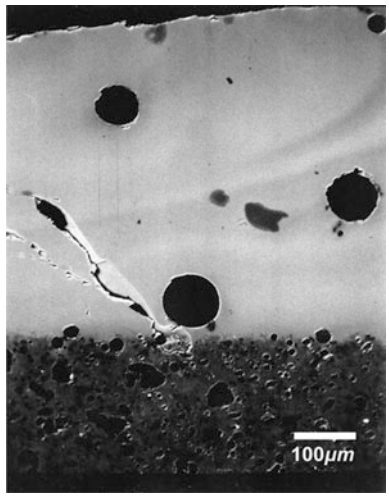
Microstructural images are various features preserved in a frozen state in the process of densification and vitrification when the firing of the



Ceramics in Korea, Fig. 25 A backscattered electron image (*BEI*) of a celadon body from Sadangni, Kangjin



Ceramics in Korea, Fig. 27 A backscattered electron image (*BEI*) of a celadon glaze from Sadangni, Kangjin

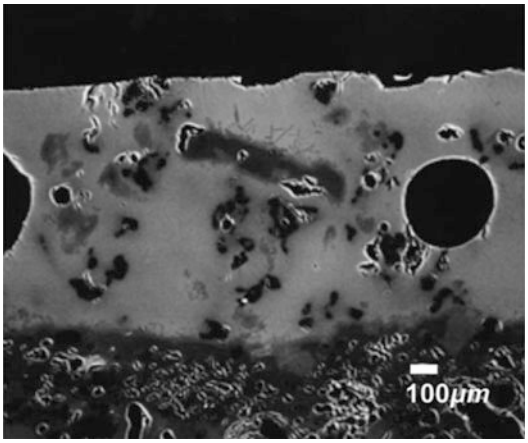


Ceramics in Korea, Fig. 26 A backscattered electron image (*BEI*) of a celadon glaze from Sadangni, Kangjin. The shard was made in Sadangni Ahredangjeon in mid-fourteenth century

ceramic pieces is stopped. A typical microstructural image of a celadon body (Fig. 25) reflects the various features of the raw material itself. The black holes in various sizes are the resultant pores that have become coalesced from innumerous small pores, and the dark-gray minerals are quartz. The matrix is made of two different phases intermixed together, the lighter ones from the melting of feldspar and the darker from the melting of the clay component.

Glaze images are shown in Figs. 26, 27, and 28. In Fig. 26 is a rare wavelike image of an unusual result called the schlieren effect. When the glaze batch is not mixed sufficiently to become completely uniform in composition, the inhomogeneous state is caught as a wave of light and dark areas. Light areas are richer in elements of higher atomic weights, and the dark areas in elements of lower atomic weights. Such an effect of inhomogeneity would have disappeared if the firing continued further. It is not clear whether such an effect was sought after intentionally or not by the potters, but the resulting microstructural feature scatters light in such a way to bring a translucent character to the celadon glaze. Bubbles of round black images, quartz minerals, and crackled line in the left lower corner also participate in the scattering of lights.

Often found in celadon glazes, especially in inlaid celadon, are images of clustered grains occurring around and underneath bubbles (Figs. 27 and 28). They are remnants of granophyric intergrowth of quartz and feldspar in glaze stone. The feldspar part is melted and incorporated into the matrix, while the quartz grains remain as dark grains. In Fig. 28 a rare rodlike



Ceramics in Korea, Fig. 28 A backscattered electron image (*BEI*) of a celadon glaze from Sadangni, Kangjin

image of muscovite mineral, which is only partially melted around its surroundings, from which are grown anorthite needles during the cooling period after the firing was stopped is also shown.

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Ceramics in Pre-Hispanic North America

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By its very nature, a synthesis of pre-Hispanic pottery technology in North America must be general in terms of both cultural areas and specific techniques. Although it is my hope to present here a fair representation of current knowledge, it is by no means meant to be a final discussion of the topic. Rather, it is my intention to provide a starting point for individuals interested in considering the multiple dimensions of indigenous pottery production in North America over time and space.

Earliest Pottery Production by Cultural Region

North America can be divided into ten broad cultural areas: Arctic and sub-Arctic, Northwest Coast, West Coast (including Baja California), Plateau, Great Basin, southwest United States, northern Mexico, the Plains, northeast United States, and southeast United States (Fig. 1). With the exception of the Northwest Coast (where only a few clay pipes and figurines have been found; Ross, 1990), all of these regions developed or adopted pottery in the pre-Hispanic era. When and how pottery production began in each region varies. In the western Arctic region (Anderson, 1980, 1984; Dumond, 1982, 1983, 1984, 1987; McCartney, 1984), pottery production appeared slightly after 3,000 years ago in association with the Norton Tradition; ceramic technology may have been introduced into the region from Siberia based on similarities in both technology and design (Zhushchikhovskaya, 1997). At about 1,500 years ago, pottery production is associated with the Thule Tradition in the Arctic; based on a few sites with apparently transitional pottery types, the Thule pottery tradition may be related to the earlier Norton Tradition (Dumond, 1984; Griffin, 1969–1970). Pottery production began as early as 2,600 years ago in the eastern sub-Arctic region (Bonnichsen, Keenlyside, & Turnmire, 1991; McGhee, 1978; Meggars, 1987; Tuck, 1999); this sub-Arctic technology is assumed to have been introduced into the region from the northeast United States even though there are few similarities in pottery from these two regions (Wright, 1981). By 2,300 years ago, pottery production spread into the central sub-Arctic region.

Ceramic material is found throughout the West Coast region in the form of pipes, figurines, small balls (possibly for use in slings), and baked clay items that may have functioned as cooking stones. The earliest pottery vessel tradition in this region, called Owens Valley brown ware, developed in central California about 500 years ago and then diffused west (Elsasser, 1978; Spier, 1978). Although there are some reports of pottery vessels in the southern coastal area dating to as early as 2,500 years ago, this technology apparently faded out and was not resumed again until about 300 years ago in the San Diego area. Pottery entered the Great Basin Region approximately 1,500 years ago with the development of the Fremont Culture (Aikens & Madsen, 1986, 1986, 1989; Marwitt, 1986; Talbot, 2000). Production techniques were probably introduced into the Great Basin Region from the southwest United States and then disappeared from the region around 1,500 years ago; the reason for this disappearance is not well understood.

Probably the most extensively studied pre-Hispanic pottery in North America comes from the southwest United States. The earliest pottery in this region dates to over 2,300 years ago and is associated with the Pioneer period of the Hohokam culture (Gladwin & Gladwin, 1933; Gumerman & Haury, 1979). At about the same time, and probably related, is the introduction of pottery production in the Mogollon cultural area (Martin, 1979; Rinaldo & Bluhm, 1956). Pottery in other areas of the southwest United States began somewhat later, with production beginning at around 1,300 years ago in both the ancestral Pueblo (Anasazi) and Patayan culture areas. It is

Ceramics in Pre-Hispanic North America,
Fig. 1 Map of North America showing prehispanic cultural regions (drawn by author).

generally assumed that pottery technology in the southwest United States was introduced into the region, possibly more than once, from what is present-day Mexico.

Dates for the introduction of pottery in northern Mexico vary by cultural area, with a better understanding for some areas than others. There is evidence that plain ware pottery was being produced as early as 2,500 years ago in the northeast Sonoran area; however, this tradition is not well understood (Douglas & Quijada, 2004). Along the Northwest Coast, pottery production began around 1,800 years ago with the production of Tiburón Plain, a thin, particularly well-made pottery type. Probably the best understood pottery sequence comes from the area around the site of Paquimé in Chihuahua, where the production of pottery began at least 2,000 years ago (Brand, 1935; Carey, 1931; DiPeso, Rinaldo, & Fenner, 1974). This technology is believed to have moved into the area along with groups moving up from Central Mexico.

Very little pottery is reported for the Plateau region: some cave sites have revealed brown-gray pottery that date from 500 to 1,500 years ago (Roll & Hackenberger, 1998). The earliest pottery on the Plains dates to approximately 2,500 years ago and is associated with different complexes depending on the cultural area. For example, the earliest pottery on the Northern Plains is associated with the Besant complex, while the earliest pottery on the southern Plains is associated with the Plains Woodland complexes to the east of the region. Depending on the area within the Plains, this early pottery shows influence from the northeast United States, the southwest United States, or both.

The oldest pottery in North America comes from Stallings Islands in Georgia (Claflin, 1932) and is believed to date as far back as 3,800 years ago (Sassaman, 1998). Pottery in northwest Florida is believed to be nearly as old, while pottery in Maryland dates to approximately 3,000 years ago (Manson, 1948). In other portions of the

southeast United States, pottery technology was adopted much later: the technology may have arrived as recently as 800 years ago in central Texas (Hughes, 1989). In the northeast United States, pottery vessels replaced soapstone vessels as early as 3,500 years ago in southern portions of the region, marking the transition between the Archaic and Woodland periods. In other areas of the northeast, pottery was adopted somewhat later: the northern portion of the region did not make ceramic vessels until approximately 2,000 years ago.

Pottery Production Techniques

Pottery production was one of the more complex technologies employed in pre-Hispanic North America. Potters took a geological material (clay) and, after preparing, shaping, and firing created a new material (ceramic). Ceramic production techniques throughout time and across North America were fairly consistent. The process of making raw clay into ceramic vessels includes five production steps: preparation of raw materials, building or shaping the clay into desired vessels forms, finishing vessels, decorating vessels, and firing.

Preparation of Raw Materials

The one required material for making ceramic vessels is clay. Clay can be found in numerous geological contexts throughout North America, from sedimentary clays in riverbeds to veins of primary clays near mesa tops. Clay is a complex geological material that has been defined by particle size, depositional context, chemical structure, and mineralogical composition. A basic definition of clay is that it is a fine-grained material formed by decomposition of high-alumina- and high-silica-bearing rocks, normally of igneous origin. Although such a definition may be useful for North American archaeologists attempting to find sources of clay used by pre-Hispanic potters, these potters used a different definition for selecting their material. The most important property of clay is that, due to its small particle size, it becomes plastic when wet. This plasticity allows some clay to be worked into desired shapes. It is this workability that would have been the defining characteristic of clays for pre-Hispanic potters. Other important characteristics for potters include shrinkage rate and amount during drying, firing behavior, texture, and impurities.

Once clay is collected from its geological source, it needs to be prepared. Preparation varies depending on the quality of the clay and what type of vessel is to be shaped. Natural or raw clays often need to be ground, cleaned, and seasoned. Although we do not know with certainty how these tasks were performed in the pre-Hispanic era, ethnographic and historical evidence concerning Native American potters provide some clues. Although clays may be soaked in water to break them down, many indigenous potters grind dry clay with either a combination of mortar and pestle or mano and metate (Shepard, 1956). Clay needs to be cleaned to remove any coarse particles that may cause a vessel to crack during drying or firing. Methods of cleaning clay vary widely, depending on the extent and size of impurities, but include handpicking, screening in baskets, and washing in water. There is no evidence that North American potters ever used levigation [freeing from grit] to clean their clays. Wet clay is then often seasoned, or soured, by storing it in a cool location for weeks or months. Seasoning clay increases its workability through bacteria growth and the complete wetting of all clay minerals through absorption.

Temper is the nonplastic material in clay. Depending on the type of temper, it can affect various attributes of the raw clay or the final ceramic product including workability, shrinkage, strength, and porosity. Some clay has naturally occurring temper, such as sand. However, potters are required to add nonplastic material to many raw types of clay before forming their vessels. Among historic and ethnographic potters, temper is added at different times during the preparation process; dry clay and temper material may be mixed during the initial grinding of the materials or ground temper may be added

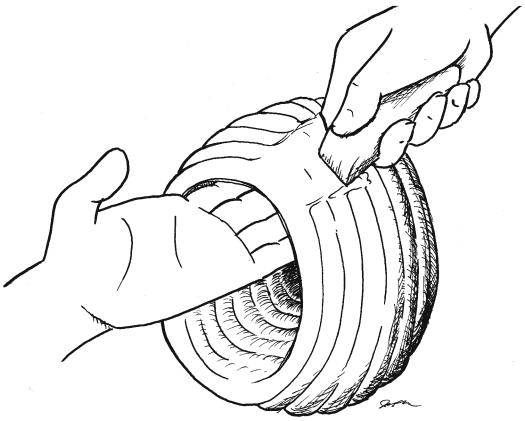
to wet clay that has already been well cleaned. Pre-Hispanic potters in North America used a wide variety of material as temper. For example, charcoal and bone were both used in the southeast United States (Wallis, 2011), while shell was sometimes used on the Plains (Henning, 2001). Sand, igneous rock, mica, and grog (crushed ceramic sherd) have all been reported from archaeological ceramic materials in the southwest United States, as well as untempered pottery (Eckert, 2008).

Shaping the Clay into Desired Vessel Forms

Once the clay has been prepared, it needs to be shaped into the desired form. In the pre-Hispanic era, the shape of a vessel was most often determined by its function; in other words, ceramic vessels were utilitarian in nature and not purely artistic. Pottery was used for many purposes, including storage, cooking, and food service. Broken pieces of pottery were often reshaped into jewelry, gaming pieces, or spindle whorls used in weaving. Common pre-Hispanic forms across North America include jars, bowls, platters, dippers (or ladles), pipes, figurines, and effigy vessels. Pre-Hispanic potters in North America never used a potter's wheel to shape their vessels; all vessels were hand built (Fig. 2). The two most common shaping techniques were coil-and-scrape and paddle-and-anvil; however, drawing-and-pinching and molding techniques were not uncommon (Figs. 3 and 4).

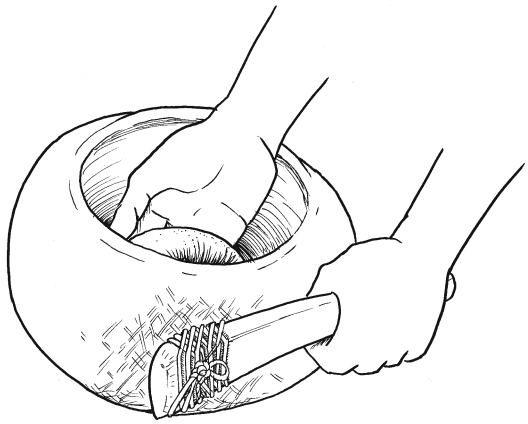
The coil-and-scrape technique involves rolling the prepared clay into ropes and then forming the vessel by successively coiling these ropes one on top of another. Alternatively, the ropes may be formed into rings that are then placed one on top of another. Vessels may be free-formed or ropes may be coiled within a preexisting vessel to help support the shape of the newly formed vessel. The joints are often smoothed over to hide the coils and strengthen the vessel walls, which are then thinned by scrapping the vessel with a tool. The use of the coil-and-scrape method in pre-Hispanic North America has been reported specifically on the West Coast, in the southwest and the southeast United States, and on the Plateau, and the Plains.

Ceramics in Pre-Hispanic North America, Fig. 2 All Pre-Hispanic pottery in North America was hand built (drawn by Joshua Keene).



Ceramics in Pre-Hispanic North America, Fig. 3 Pottery vessel smoothed and thinned using coil-and-scrape method (drawn by Joshua Keene).

The paddle-and-anvil technique involves the potter's taking a mass of prepared clay and then drawing pieces of the clay upwards into the desired vessel shape. In order to thin the walls of the vessel, the exterior surface is slapped with a paddle against an anvil held against the interior surface. Paddles were normally made out of



Ceramics in Pre-Hispanic North America, Fig. 4 Pottery vessel smoothed and thinned using paddle-and-anvil method (drawn by Joshua Keene).

wood and often wrapped with cord or a textile. Anvils could be made from a variety of materials, including wood, clay, or stone. The use of the paddle-and-anvil technique by pre-Hispanic potters has been reported for southern Canada, the southwest United States, northern Mexico, the southeast United States, portions of California, and on the Plains.

Drawing-and-pinching is probably the simplest way to shape clay. A lump of clay is placed on a surface, or held in one hand, while the other hand is used to form an indent in the center of the lump. The potter then pulls (draws) and squeezes (pinches) the clay with one or both hands, while turning the lump of clay, to shape the clay into the desired vessel form. Further pulling and squeezing helps to hollow out and thin the vessel walls. The amount of pinching versus drawing depends on the size of the desired vessel. Pinching is used primarily to form small vessels that can be held in the hand, while drawing is used primarily to form larger vessels that sit on a surface. Drawing-and-pinching can also be used to create the base of vessels that will be further formed using other shaping techniques. Evidence for the use of drawing-and-pinching in the pre-Hispanic era has been reported from all regions of North America.

Molding can also be used to form a vessel. Vessels are shaped by pressing clay into premade containers of the desired form. The use of complex, multiple piece molds was not practiced in pre-Hispanic North America, with the possible exception of northern Mexico. Instead, simple shapes such as pottery vessels or woven baskets appear to have been used as molds, especially on the Plains, and in the southeast and southwest United States. As with drawing-and-pinching, molding may have been used to form the base of vessels that would then be completed using either the coil-and-scrap or paddle-and-anvil technique.

Finishing Vessels

Once a vessel has been shaped, at least one surface of the vessel is usually finished. Depending on the finishing technique, a potter may choose to finish a surface, while the clay is still wet and plastic, or may choose to wait until the vessel has been dried and the clay is leather hard. Finishing techniques serve primarily to improve the quality of a vessel's surface by removing irregularities that may have been created during the forming process. The choice of finishing techniques relies on the intended purpose of the vessel, whether or not the potter intends to decorate it and, if so, the decorating technique to be used. Finishing techniques used by potters throughout pre-Hispanic North America included smoothing, slipping, and polishing, although the popularity of any single technique varied by cultural region.

Smoothing entails evening out the surface of a vessel with the palm of the hand or with a tool such as a smooth pebble, the smooth surface of a potsherd, or a corncob. Smoothing a surface can be accomplished while the clay is still wet, in which case it is often done as part of the forming process. Smoothing can also be accomplished once the clay is leather hard; however, the application of water to the surface intended to be smoothed in usually necessary once the vessel is dry. Either way, smoothing serves to level ridges and fill depressions, resulting in an even surface.

Slipping involves the application of watered-down clay to the vessel surface. Often, the clay chosen as a slip is not the same clay chosen for the forming of the vessel. A vessel may be slipped to

enhance its appearance by creating a uniform surface; if a slip is thick enough, it hides the temper and other inclusions in the clay used to form the vessel. A slip may also be applied to make the vessel surface, or portions of the surface, a specific color. Finally, a slip may be added to a surface to prepare the vessel for further decoration. A slip may be applied by dipping the vessel into the slip, by pouring the slip over the vessel, or by washing it onto the vessel with the palm of the hand or a rag. Once a slip is applied to a vessel, the surface of the vessel may be polished.

Polishing a vessel serves to give the surface a fine luster. Among historic and ethnographic potters in North America, polish is usually achieved by vigorously rubbing the vessel surface with a smooth stone (Shepard, 1956). Polishing can be accomplished when the clay is still moist or when it is leather hard. Although the surface of a vessel can be polished with or without a slip, it must be well smoothed before polishing can begin. If the surface is uneven, depressions will not be polished, resulting in dull spots, while ridges or inclusions may be pulled, resulting in drag lines.

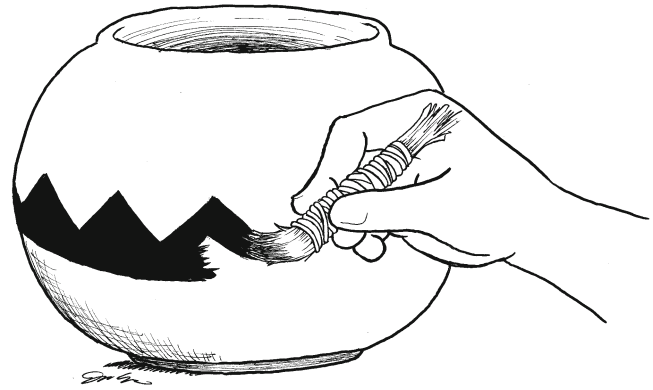
Decorating Vessels

Although not affecting the function of a vessel in any way, many pre-Hispanic potters chose to decorate their products. Decorations may have had social, religious, economic, or personal significance to the potter. The numerous styles of decoration employed by potters represent the greatest diversity to be found in pottery production in pre-Hispanic North America but is not to be elaborated upon here. The techniques of decoration, however, were limited to the use of coils, surface texturing, painting, and appliqué.

When vessels are formed using the coil-and-scrape method, potters are faced with the decision to smooth the coils or to leave the coils visible. Smoothing the coils increases the strength of the vessel, while leaving the coils visible increases the surface area of the vessel. This latter characteristic is desirable in vessels to be used for cooking. If a potter chooses to leave the coils visible, she can decorate the coils with various finger indentations or tooled patterns. She can also vary the width of her coils. This technique of decorating a vessel with the coils was well established in the southwest United States, where the corrugated brown wares of the Mogollon culture were some of the finest vessels made in pre-Hispanic North America (Rinaldo & Bluhm, 1956).

The smoothed surface of a vessel can be decorated with various types of texturing. Pieces of textiles, carved wood, or other textured tools can be used to decorate wet clay through stamping, as was common on decorated pottery produced in the Arctic region (Dumond, 1982). On the Plains and in the northeast United States, many vessels were decorated by the impressions left on the exterior surface of the vessel from the paddle used to form them. Paddles were wrapped in cord, netting, or different textiles to create different surface designs on the vessels. Throughout North America, potters gouged, scored, grooved, carved, and incised various designs on their vessels using their fingers or sharps tools. Depending on place and time, these various designs were created when the vessel was still wet, when it was dried to leather hard and, in some instances, once it had been fired.

Painting a vessel requires the application of a pigment to create a design (Fig. 5). Paint can be applied with a finger, with a soft tool such as animal hair, or with a hard tool such as a smoothed piece of bone. Paint can be applied before firing, during the leather-hard stage of production, or after a vessel is fired. In some ethnographic instances, paint is applied after the first firing, and then the vessel is fired a second time to bind the paint to the surface (Fewkes, 1944). Two common types of paints were used throughout pre-Hispanic North America: carbon paint, which was made from organic material, and mineral paint, which was made from nonorganic material. Carbon paint was only applied if a reducing atmosphere was used during firing; in an oxidizing atmosphere, the carbon would have burned away. Further, in the



Ceramics in Pre-Hispanic North America, Fig. 5 Paint can be applied in a variety of ways, including using a soft brush made of animal hair or plant fibers (drawn by Joshua Keene).

southwest United States, the technology to create glaze paint was developed.

Appliqué involves attaching pieces of clay to a vessel as decoration; unlike the decorative techniques described above, appliqué results in a three-dimensional effect. Throughout pre-Hispanic North America, appliqué was never a primary decorative technique; however, its use has been reported from archaeological context in most cultural regions. The appliqué was often shaped into animal or human forms but was sometimes added simply as trim. In some instances, the appliqué is painted with details, such as eyes or ears.

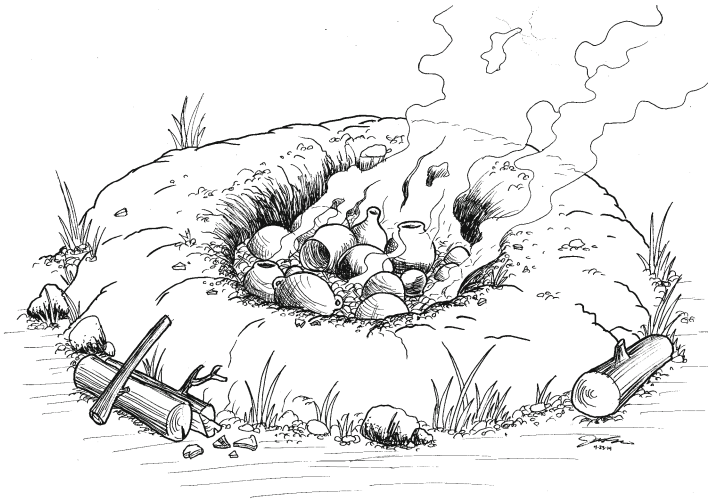
Firing

Once a vessel has been formed, decorated, and dried to the leather-hard stage, it is fired. It is during firing that the clay material undergoes the chemical change of vitrification (the point at which a pot loses its porosity during firing) and becomes ceramic material. Ceramic material is harder and more brittle than clay, it is often more porous, and it does not become plastic with the addition of water. Although the use of a formal kiln was rare in pre-Hispanic North America, potters still had the same concerns when firing their products as modern potters do: retention of heat, control of draft, and control of atmosphere.

Retention of heat is important because if a vessel is not fired at a high enough temperature for a long enough period of time, the clay does not vitrify and become ceramic material. Specific temperatures and length of firing depends upon the properties of individual clays. The most common "kiln" in pre-Hispanic North America was the pit kiln (Fig. 6). Potters would have dug a pit into the ground; a fire would have been built into the pit and the vessels placed upon the charcoal from this fire, with further charcoal being placed around and on top of the vessels. Alternatively, the vessels may have been placed within an unfired pit, and then charcoal would have been stacked around the vessels. Although various types of fuel may have been used – including hard wood, coal, and dung – the main requirement of the fuel was that it smoldered. Pottery may also have been fired above ground, with fuel simply being placed under and around the vessels.

It is important to control air drafts to insure even firing and to avoid surface discolorations that are the result of soot coming into contact with the vessels. Although it is easier to control drafts in formal kilns, pre-Hispanic potters using pit kilns or firing above ground had a number of options. If the fuel and vessels were placed appropriately within a pit kiln or above ground, an updraft could have been created that would allow for more even firing, avoid the problem of sooting, and help control the firing atmosphere. To avoid a cross draft, potters could have fired their vessels in areas that were sheltered from the wind or in seasons that were particularly calm.

Pre-Hispanic potters also needed to control the firing atmosphere within their informal kilns;



Ceramics in Pre-Hispanic North America, Fig. 6 Example of an open pit kiln.

specifically, they needed to worry about the amount of oxygen that entered into the firing atmosphere. They needed to create an oxidizing atmosphere that was sufficiently hot enough for a long enough period of time to completely burn out all organic material. If organic material remains in a vessel during the vitrification process, the vessel surface may bloat and potentially break. Controlling the amount of air in the firing atmosphere for a long enough period of time requires a well-controlled draft as well as the possible need to add fuel. Alternatively, some pre-Hispanic potters fired their vessels in a reducing atmosphere, one in which no oxygen entered the kiln. This is a much more difficult firing atmosphere to obtain in pit kilns, as the fuel must smolder long enough and hot enough for the clay to vitrify into ceramic material, but at the same time no air can be allowed to enter into the system. A reducing atmosphere, although not as hot as an oxidizing atmosphere, allowed for the creation of specific decorative affects including the use of carbon paints and the creation of white slips.

During the firing process, a potter may have chosen to smudge her vessels. Smudging is the process of blackening the surface of a vessel through the deposition of soot. In other words, rather than avoid the discoloration of sooting, some potters appear to have chosen to do this intentionally. By bringing the vessel surface into contact with the smoldering fuel, and keeping the vessels in a reducing atmosphere, carbon penetrates into the pores of the vessel and turns it permanently black. Potters of the Mogollon culture of the southwest United States developed particularly fine smudged wares, with the entire interior surfaces of their vessels being a dark, even, glossy black.

Although the timing of the adoption of pottery production varies by region, the knowledge of how to produce pottery throughout North America appears to have been gained through diffusion rather than being independently developed. Vessels throughout the continent were hand built, often through either the coil-and-scrape or paddle-and-anvil technique. Once a vessel was formed, decisions on how to finish and decorate a vessel were limited to a handful of techniques. Firing methods were simple, never proceeding beyond pits or simple kilns. Overall, despite the apparent diversity of pottery types that were produced across pre-Hispanic North America, the methods used to produce these vessels were relatively homogenous.

See Also

► Ceramics: Mimbres Pottery

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Ceramics in Southeast Asia

Dawn F. Rooney

The mainland region of Southeast Asia has a rich, indigenous tradition of ancient ceramic production with centers in the modern nations of Cambodia, Lao People's Democratic Republic (Laos), Myanmar (Burma), Thailand, and Vietnam. The main output was ware for domestic and ritualistic use and regional trade. The insular Southeast Asian region (Brunei, East Timor Indonesia, Malaysia, Philippines, Singapore) made only utilitarian earthenware such as cooking and storage vessels for foods and liquids. It did, though, import trade ceramics from the mainland, China, and Japan beginning in the fourteenth century.

By the second millennium BCE inhabitants of early rice-agriculture settlements in Southeast Asia were making similar types of red-slipped, painted, stamped, and cord-marked pottery. Roulette-made ware from India found in Java and Vietnam testify that trade contacts between India and Southeast Asia were established by the last century BCE.

Ban Chiang, Udon Thani Province, Northeastern Thailand, is a representative, prehistoric site for the region. Excavations of burials conducted between 1974 and 1986 yielded tons of shards. Various forms of vessels with geometric designs painted in red on a buff-colored body were made using the anvil and paddle technique. The site is dated from BCE 3600 to AD 200.

The prehistoric tradition of making indigenous pottery in Southeast Asia continued into the next period. Thousands of shards unearthed at Angkor Borei, Ta Keo Province, southern Cambodia, are typical pottery of the early historic period, particularly the spouted vessel (*kendi*) with a bulbous body and a spout on the side, which is a ubiquitous form at all early sites in Southeast Asia (Fig. 1).

The earliest transitions from low-fired, unglazed to high-fired glazed ware occurred in Cambodia and Myanmar between the eighth and ninth centuries AD.

Cambodia

Green-glazed roof tiles from temples of the Angkor Period (AD 802–1432) capital of Hariharalaya (now Roluos), built by King Indravarman I (r. AD 877–889), attest that the Khmers were making glazed stoneware by the late ninth century. Their repertoire expanded to include brown-glazed ware in the eleventh century. Ceramic production in Cambodia continued at least until the end of the thirteenth century. Although the Khmer Empire lasted for another 150 years, ceramics have not yet been positively attributed to the later period.

The first discovery of kilns producing Angkor Period ceramics was in the 1970s in Northeastern Thailand on the Khorat Plateau, an area that was part of the Khmer Empire between the eleventh and the thirteenth centuries. Kilns in Cambodia, however, were not confirmed until 1995.

Ceramics in Southeast Asia, Fig. 1 Spouted vessel (*kendi*). Earthenware. Sisophon, Cambodia. ca. AD sixth century

Groslier proposed the first chronology for Khmer ceramics. He analyzed types of glazes on wares found in excavations in the mid-twentieth century at the Angkor Period Royal Palace compound and in a burial at Srah Srang, the royal bath. Brown published a later refinement of Groslier's chronology (1981).

Two extensive kiln sites have been identified in Buri Ram Province – Ban ("village") Kruat and Ban Baranae. The oval-shape, crossdraft kilns were built of clay slabs with two chambers and a chimney. Both made green- and brown-glazed ware.

Over 12 groups of kilns operating during the Angkor Period in Cambodia have been identified in Siem Reap, Banteay Meanchhey, and Kandal provinces. Anlong Thom, on the southern ridge of Phnom ("Mount") Kulen, 25 mile (40 km) northeast of Angkor, produced high-quality, green-glazed stoneware. The main shapes were architectural fixtures (tiles and finials), covered jars, and bowls (Fig. 2).

The iron-rich body of Khmer stoneware is gray with impurities. Larger vessels were coil-built; smaller ones were thrown on a wheel. The glaze was either brown or green with fine-line cracks. Flaking of the glaze is a common defect. Decoration is always minimal and consists of repetitive geometric patterns encircling the neck, shoulder, or body (Fig. 3).

Ceramics in Southeast Asia, Fig. 2 Green-glazed roof tile. $L = 7.5$ in. (19 cm). Khmer. Tenth century

Some Khmer forms, uncommon in other ceramic traditions of Southeast Asia, may have metal prototypes. Examples are:

- A green-glazed cylindrical covered jar and a bowl with slightly flaring walls and unglazed firing scars around the lower body
- A brown-glazed flattened globular pot with a broad shoulder, a flat base, and a narrow mouth with a rolled rim
- A footed jar with a round body, a flat shoulder, tubular neck, flaring mouth with a flange, and a pedestal base
- Small pots with animal-shape (birds, elephants, rabbits) appendages (Fig. 4)

Laos

Excavations conducted at Sisattanak, near the modern capital of Vientiane in Lao People's Democratic Republic (Laos), in 1970 and 1989 identified a kiln site that operated between the fifteenth and seventeenth centuries based on

Ceramics in Southeast Asia, Fig. 3 Brown-glazed storage jar. $Ht = 26$ in. (66 cm). Khmer. Twelfth century

Ceramics in Southeast Asia, Fig. 4 Brown-glazed footed jar. $H = 16$ in. (40.6 cm). Khmer. Late eleventh century

Ceramics in Southeast Asia, Fig. 5 Unglazed pipe. Stoneware. $L = 3.5$ in. (8.9 cm). Laotian. Seventeenth Century

radiocarbon dating of associated finds. Quantities of unglazed and brown-glazed stoneware shards and wasters were spread over a wide area. The shapes are utilitarian and include bowls, dishes, jars, and pipes (Fig. 5).

Myanmar (Burma)

Architectural plaques and tiles (unglazed and glazed) were used on temples at Bagan (formerly Pagan) in the eleventh century. Geometric tiles are square, round or octagonal and decorated with applied lotus leaves or a lozenge with a blue-green glaze and yellow and white accents. Pictorial plaques portray episodes from the Buddha's former lives (Fig. 6).

Myanmar archaeologists recently discovered hundreds of ancient kilns in Twante district, approximately 11 mile southwest of the capital, Yangon (formerly Rangoon). They produced only celadon and probably operated between the fifteenth and seventeenth centuries. Previously

Ceramics in Southeast Asia, Fig. 6 Glazed tiles at Naga-yon temple. Bagan, Myanmar. Eleventh Century

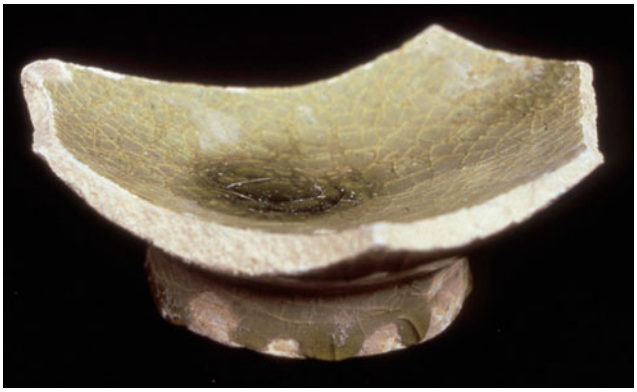
Ceramics in Southeast Asia, Fig. 7 Excavated kiln at Twante, Myanmar. Fifteenth to seventeenth centuries

unidentifiable celadon found in burial sites in Indonesia, the Philippines, and Tak and Om Koi are now attributed to Myanmar.

Two kilns were excavated in 1999. The characteristics are (1) oval-shape, (2) crossdraft, and (3) built of clay slabs on a slope with two chambers separated by a low wall and a chimney. An unusual feature of the Twante kilns is the remains of columns in the firing chamber, which were probably used to support a dome-shaped cover. The kiln dimensions are 39 × 16 ft (11.9 × 4.9 m). Tubular, clay supports were used to stack the ware. The body contains quartz, other silica, and a high concentration of iron. The characteristics after firing in a reducing atmosphere to a stoneware temperature are: a nonporous body and a wood-ash glaze with iron that produced a transparent, green color. Pooling of the glaze is common. Forms are medium-sized vessels that were hand-built or thrown on a potter's wheel. Typical shapes are simple bowls, dishes, and plates with minimal geometric decoration (Figs. 7 and 8).

Other known kiln sites in Myanmar include: Lagunbyee, a former Mon center, southwest of Bago (formerly Pegu) where remains of a brick, crossdraft kiln were discovered in 1987 and excavated in 1998–1999; the kiln is 120 × 70 ft (36.6 × 21.3 m) and provisionally dated between the eleventh and the thirteenth centuries. Ten kilns and firing supports have been discovered at Myaung-Mya, west of Yangon, near Bassein.

Although kilns have not been found, it is certain that distinctive earthenware with an orange body and an opaque white, vibrant red, or green glaze was made in Myanmar. A variation is a design painted in green under the white glaze (Fig. 9).



Ceramics in Southeast Asia, Fig. 8 Celadon bowl (shard). Twante, Myanmar. Fifteenth to seventeenth centuries

Ceramics in Southeast Asia, Fig. 9 Green and white earthenware shards. Myanmar. Fourteenth to sixteenth centuries

Thailand (Sawankhalok or Si Satchanalai Ware)

Three sources have enabled recent advances in our knowledge of ancient ceramic production in Thailand: underwater archaeology in the Gulf of Thailand where 130 shipwrecks have been reported; excavations of kilns at Sawankhalok and surveys in satellite areas – Phitsanulok, Suphan Buri, and Sing Buri; and ceramic finds in burials at Tak and Om Koi, western Thailand, near the Myanmar border. The quality of ware from the latter is extremely fine and the wide range includes ceramics from China, Vietnam, Thailand, Cambodia, and Myanmar.

Glazed architectural fixtures were made in the late thirteenth century for the temples of the burgeoning Kingdom of Sukhothai in north-central Thailand (279 mile (449 km) north of the modern capital of Bangkok). As the kingdom expanded, a second city developed at Si Satchanalai, 43 mile (69 km) north of Sukhothai, where kilns producing glazed ceramics were also set up. In the middle of the fourteenth century when Sukhothai became vassalage of the southern Kingdom of Ayutthaya, 49 mile (79 km)

Ceramics in Southeast Asia, Fig. 10 Excavated kiln at Ban Ko Noi. Sawankhalok, Thailand. Fourteenth to fifteenth centuries

inland from the Gulf of Thailand the place name "Si Satchanalai" was changed to "Sawankhalok." Today, either name is acceptable when referring to the kiln site and the wares. The kilns continued to operate at least through the sixteenth century despite the shift in power.

The dates of operation for the two ceramic centers are not conclusively known. Evidence from shipwrecks carrying ceramics found in the Gulf of Thailand reverses a previously held theory and confirms that the Sukhothai kilns began production later than those at Sawankhalok. During the peak period for the export of ceramics from north-central Thailand (fifteenth and early sixteenth centuries) an estimated 1,000 kilns were operating. Changes in social, economic, and political circumstances of the kingdom most likely impacted on the kilns, causing a gradual decline in ceramic production.

Some 800 kilns have been discovered in the modern village of Ban Ko Noi, 4 mile north of the old city wall on the banks of the Yom River. Ban Pa Yang, a smaller kiln site in the area, produced architectural fixtures, human and animal figures, and brown- and white-glazed trade ware.

Kiln technology at Sawankhalok evolved from a simple bank kiln for firing unglazed, low-fired ware to one constructed of clay slabs that was more sustainable and could hold larger vessels. Finally there was a crossdraft kiln built of prefired bricks. A typical kiln of the latter type is oval shape, crossdraft with a sloping chamber for the wares in the center, a recessed fire-box at one end, and a round chimney at the other. A typical kiln was 29 × 11 ft (8.8 × 3.4 m). For firing, a fixative was applied to the base of a vessel, which was then placed on top of a tubular clay support that was sunk into the sandy floor of the kiln. A black ring on the unglazed base resulted from the fixative of the vessel after firing (Figs. 10 and 11).

Green-Glazed Ware (Celadon)

Sawankhalok celadon is the most widely known product of the ancient Thai kilns. An iron-rich glaze was mixed with ash and fired in a reducing atmosphere. The thick, translucent glaze varies in color from a sea green to olive. Motifs incised in the center of plates and bowls, around the cavetto (a hollow or concave molding in the form of a quadrant) and rim, and on the exterior, drew inspiration from the regional flora, such as lotus and peony. Primary shapes are plates, bowls, bottles, kendis, and jarlets (a small, squat, rounded, or square jar with a small mouth) (Fig. 12).

Brown and White Ware

Sawankhalok kilns produced two other monochrome glazes – brown and white. A typical brown-glazed form is a jar with a tall body, a thick-rolled mouth rim and two handles. A combination of the two glazes on a single piece was a specialty of the export ware made at the Ban Pa Yang kilns (Fig. 13).

Exceptionally large water jars were also made (Fig. 14).

Architectural fixtures, such as tiles, were usually white-glazed (Fig. 15).

Ceramics in Southeast Asia, Fig. 11 Tubular support for celadon bowl; scar after firing. Sawankhalok, Thailand. Fifteenth century

Ceramics in Southeast Asia, Fig. 12 Celadon plate. Diameter = 11 in. (28 cm). Sawankhalok. Fifteenth century

Quantities of figures (animal and human) were made at Tukatha (Ban Pa Yang kiln site) for the religious and cult needs of the native inhabitants (Fig. 16).

Iron-Decorated Ware

A design was painted on the body with iron oxide; then a transparent clear glaze applied over it. Sometimes a slip was put on the body for a lighter color which created more contrast between the design and the background. Forms include plates, bowls, bottles, kendis, and architectural fixtures. A particular type of round covered box was produced prolifically for export.

Ceramics in Southeast Asia, Fig. 13 Brown-glazed jar. $H = 5$ in. (13 cm). Sawankhalok. Fifteenth century

The body and cover of the box form a continuous line with modeled knob on the cover that is shaped like a lotus bud or in the form of a fruit stem (Fig. 17).

Ceramics in Southeast Asia, Fig. 14 Brown-glazed storage jar. $H = 3$ ft. Sawankhalok. Fifteenth century

Ceramics in Southeast Asia, Fig. 15 White-glazed tile. $H = 4$ in. (10 cm). Sawankhalok. Fourteenth century

Ceramics in Southeast Asia, Fig. 16 Brown-glazed chicken. $L = 3$ in. (7.6 cm). Sawankhalok. Fourteenth century

Ceramics in Southeast Asia, Fig. 17 Underglaze glaze painted box with cover. Diameter = 4 in. (10 cm). Sawankhalok. Fifteenth to sixteenth centuries

Thailand (Sukhothai Ware)

Two clusters of over 50 kilns have been identified at Sukhothai – one near Wat ("temple") Prah Phai Luang and another north of the city wall. The kiln

Ceramics in Southeast Asia, Fig. 18 Disc firing support. Diameter = 4 in. (10 cm). Sukhothai. Fifteenth century

Ceramics in Southeast Asia, Fig. 19 Painted shard. Sukhothai. Fifteenth century

shape and construction are essentially the same as those at Sawankhalok except the Sukhothai kiln is narrower. The average dimensions are 29 × 8 ft. Plates and bowls were stacked for firing by placing one on top of the other separated by a disc-shaped clay support with spurs (usually five). A distinctive feature in the center of Sukhothai plates and bowls is five circular scars resulting from separating the disc after firing (Fig. 18).

Sukhothai kilns produced two types of ceramics – painted ware and a white-glazed ware. To achieve the former, a slip was applied to a dark body; next, a design was painted using iron oxide; then a thin, transparent glaze was applied. After firing, the texture of the gray body was coarse with visible white flecks of quartz; the color of the iron pigment varied from gray to olive, brown or black; and the glaze is often opaque, or milky in appearance with fine-line crazing and pin holes. A painted fish plate (average diameter = 10 in. (25 cm)) is characteristic of the Sukhothai kilns. The central motif is a single fish, painted in profile, and encircled by one or more rings. Other designs on plates, bowls, and a few bottles such as a single stemmed flower surrounded by leaves and a solar whorl and architectural forms were made at Sukhothai (Fig. 19).

Thailand (Suphan Buri Ware)

A complex of kilns at Ban Bang Pun in Suphan Buri Province, northwest of Ayutthaya, was discovered in the 1980s. The main output was unglazed stoneware footed jars, which were previously attributed to Sawankhalok or Sukhothai. Distinctive, repetitive bands of a leaf motif were stamped around the base of the neck and outer shoulder. The crossdraft, clay kilns were of a similar design to those at Kalong in northern Thailand.

Thailand (Phitsanulok and Nakorn Thai Ware)

Phitsanulok, a small state east of Sukhothai and controlled by the Sukhothai Kingdom in the thirteenth century, became a provincial capital of the Ayutthaya Kingdom in the fifteenth century. Excavations in 1984 at Ban Tao Hai ("village of the jar kilns") on the eastern bank of the Nan River, 2.5 mile (4 km) north of the modern town of Phitsanulok, revealed two brick, crossdraft kilns of the type developed at Ban Ko Noi with another estimated 40 kilns in the area. A typical jar is baluster-shaped with a flaring mouth and applied decoration. The kiln structure and the output suggest the site operated in the late fourteenth or early fifteenth century.

Ceramics in Southeast Asia, Fig. 20 Excavated kiln at Sankampaeng. Northern Thailand. Mid-fourteenth to mid-sixteenth centuries

The identification of six kilns at Nakorn Thai, east of Phitsanuloke, indicates that it was also a production center for stoneware jars with dates of operation the same as the Phitsanulok kilns.

Thailand (Northern Thai Ware)

Lan Na, founded by King Mengrai in 1292, with a capital at Chiang Mai in Northern Thailand, was an extensive ceramic center making glazed stoneware for domestic and ritualistic needs between the mid-fourteenth and the mid-sixteenth centuries.

The northern kilns were dug from river banks, or made with clay slabs in-ground, or brick-constructed above ground. General characteristics are: small size, simple construction, and crossdraft with two chambers and a chimney. Plates, dishes, and bowls were stacked in the kilns lip to lip and base to base.

Kalong

Over 200 kilns are mid-way between Chiang Mai and Chiang Rai near the valley of the Lao River. Kalong kilns produced ware painted with iron oxide under the glaze in the style of those from north-central Thailand but with more flamboyant motifs executed with broader brush strokes. Dishes with an abstract leaf and flower design are typical. The Kalong kilns also made a fine, thinly potted ware covered with a soft rain-cloud gray glaze. Vases, bowls, bottles, and dishes comprise this group.

Sankampaeng, Phayao, Nan

Eighty-three kilns are located by the Ping River valley, approximately 15 mile (24 km) east of Chiang Mai. Average dimensions of a kiln are 10 × 4 ft (3 × 1.2 m). Plates and dishes (either painted or brown-glazed) with a central medallion of two fish are typical Sankampaeng ware. Celadon, painted ware, and two-color jars were also common (Figs. 20 and 21).

Kilns were reported at Phayao, in Cham Pawai district, near the remains of an ancient walled city, in the 1950s. The site is unexcavated but shards of celadon, brown-glaze, and two-glaze wares have been found. Stamped motifs and incising through a slip are distinctive characteristics of Phayao ware.

An extensive kiln site was found at Nan, western Thailand, in 1982. It produced painted ware (underglaze black) with a milky white glaze that was placed in a sagger (a box of baked fireproof clay used to protect pieces during firing) for protection during firing.

Phan

Twenty-seven brick kilns situated between Chiang Rai and Phayao are of the crossdraft type with the average dimensions of 20 × 11 ft (6 × 3.4 m). The Phan kilns only produced celadon. It is more carefully potted and more finely

Ceramics in Southeast Asia, Fig. 21 Brown-glazed plate. Diameter = 9 in. (23 cm). Sankampaeng, Northern Thailand. Mid-fourteenth to mid-sixteenth centuries

finished than other northern wares. The shapes include plates, bowls, jars, oil lamps, miniatures, elephants, and kendis. The sophistication and the narrow range of these wares suggest a slightly later date, perhaps from the mid-fifteenth to the mid-sixteenth century.

Thailand (Lamphun (Haripunjaya) Ware)

Although no kilns have been found, shards litter the area of Lamphun, the old Haripunjaya kingdom, and similar ones were found at Tak and Om Koi. These finds suggest a mid-fourteenth to mid-sixteenth century date. The finely textured body is either orange or brownish black. A typical form is a thinly potted, globular, long-necked bottle with a flat base, inlaid with slip, and either intricate white or black geometric motifs on the neck and body.

Thailand (Sing Buri or Maenam Noi Ware)

Excavations conducted in 1987 in Bang Rachan district of Sing Buri Province at the Tao Maenam Noi kiln site established the provenance of a class of brown-glazed storage jars previously believed

Ceramics in Southeast Asia, Fig. 22 Brown-glazed jar. H = 18 in. (45.7 cm). Sing Buri, Thailand. Late sixteenth to early seventeenth centuries

to be Sukhothai. As the kilns are located near a temple, the ware is popularly called Wat ("temple") Phra Prang Pottery. The oval-shape, crossdraft, brick kiln measures 44 ft (13.4 m) long and is the largest one found so far in Thailand. Both unglazed and glazed ware was made, mostly storage jars but also unglazed kendis. A typical jar is heavily potted, with an ovoid body and a narrow neck with a rolled lip and partially covered with a brown glaze. These jars have been found in the cargo of a number of shipwrecks in the Gulf of Thailand dating to the late sixteenth or early seventeenth centuries (Fig. 22).

Vietnam

The glazed ceramic tradition of Vietnam is unlike any other in Southeast Asia as it was strongly

Ceramics in Southeast Asia, Fig. 23 Green-glazed lime pot. $H = 7$ in. (18 cm). Vietnamese. Fifteenth to sixteenth centuries

influenced throughout history by China, both technically and stylistically. Its development, forms, and motifs, therefore, are parallel approximately that of Chinese ceramics. Extensive excavations of burial grounds in the early twentieth century in Thanh-hoa Province, northern Vietnam, yielded quantities of ceramics dated between the tenth and the thirteenth or fourteenth centuries. Kilns near the modern city of Hanoi, the site of capitals of the Ly (AD 1009–1225) and the Tran (1225–1400) dynasties, were most likely the source of the Thanh-hoa ware. Vietnamese ceramics entered the export market in the fourteenth or early fifteenth century with painted ware in both underglaze blue and black. Despite the Chinese influence, some forms are distinctively Vietnamese. A storage container for lime to use for betel chewing is an example. The squat form has a small opening on the shoulder, a pedestal foot, and a "basket-like" handle with elaborate decoration. Ritualistic ceramics made in the late sixteenth or seventeenth century at kilns near Hanoi are distinguished by large altar vases and incense burners (Fig. 23).

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Ceramics in the West Indies

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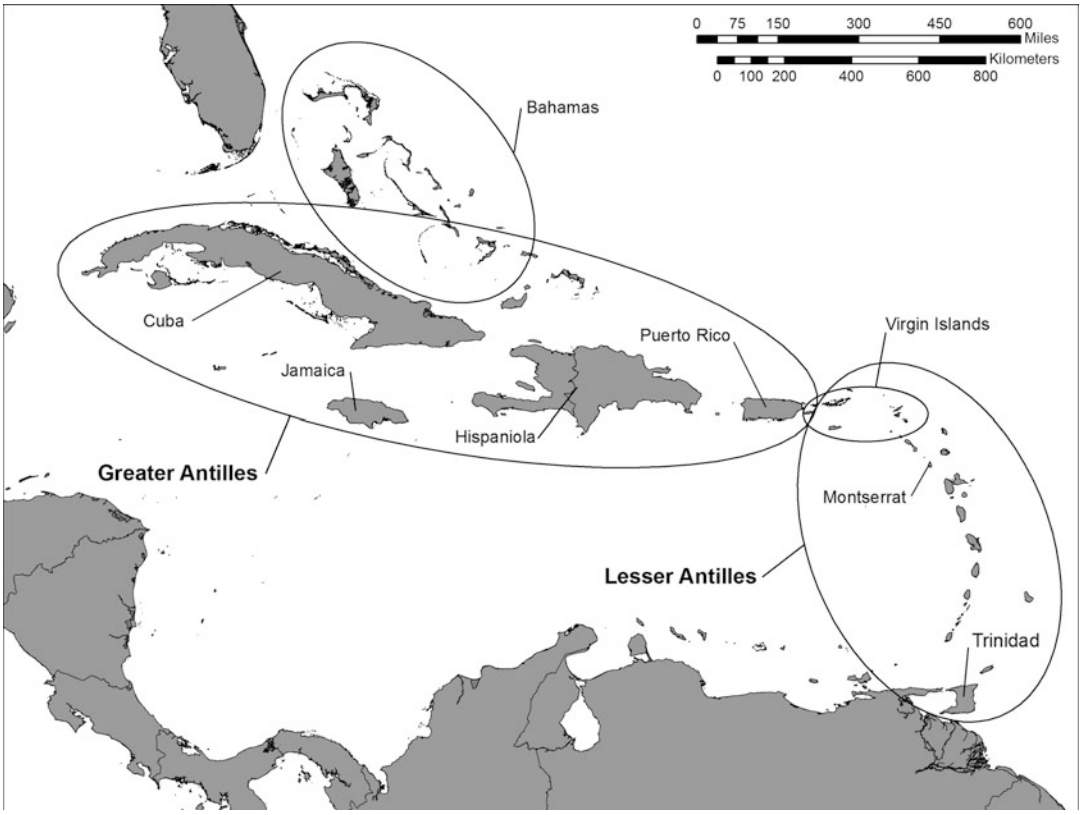
The West Indies are a series of 28 island nations and over 7,000 islands in the Caribbean Sea and Atlantic Ocean between North and South America (Fig. 1). The islands include the Greater Antilles, which are the more northern and larger islands of Cuba, Hispaniola, Jamaica, and Puerto Rico, and the Lesser Antilles, which are the islands from the United States Virgin Islands south to Trinidad. The West Indies also include the Bahamas, Aruba, Bonaire, and Curacao. The islands vary in size, topography, and proximity to one another, which has had an influence on prehistoric and historic settlement, subsistence, and material culture. Pre-Columbian pottery in the West Indies is very diverse due to the geographical breadth of the region and influences from South and Central America and possibly North America. After European contact, the many islands were colonized by the Spanish, British, French, and Dutch, and the Amerindian populations in the West Indies were quickly decimated on most islands. A plantation economy was soon in place where enslaved Africans worked the sugar, tobacco, spice, coffee, cotton, and indigo plantations.

The West Indies were first settled from South America around 7,000 years ago and from



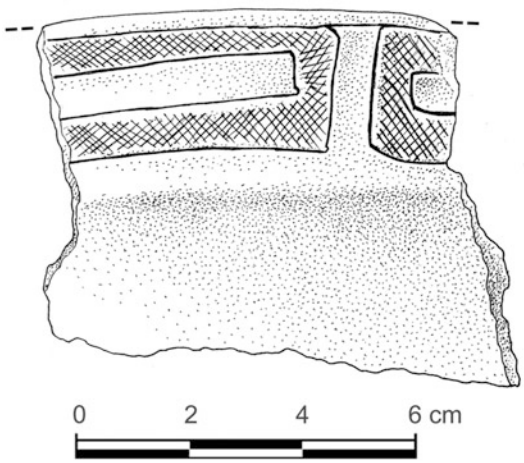
Ceramics in the West Indies, Fig. 1 Location of West Indies with subregions and islands mentioned in text identified

Central America about 6,000 years ago. The first settlers of the West Indies engaged in marine and terrestrial subsistence with material culture of ground stone, coral, and shell tools. The paucity of quality cryptocrystalline stone meant that stone tools were not widely used. Pottery first appears in the West Indies as early as 800 BC during the Saladoid period. The Saladoid takes its name from the type site in the Orinoco valley of Venezuela where it is thought the people who brought ceramics to the West Indies originated. The earliest known Saladoid sites are in Montserrat, St. Martin, Puerto Rico, and the Virgin Islands.

The Saladoid period is marked by horticulture, hunting and fishing, permanent villages, and pottery. The presence of griddles indicates the cultivation of manioc roots as well as other root and vegetable crops. Pottery is the defining feature of the Saladoid period and includes a variety of plain as well as highly decorated pieces. Early Saladoid pottery is marked by white-on-red painted decorations, modeled-incised adornos, and zone-incised cross-hatching (Fig. 2). After AD 400, Saladoid pottery becomes thicker and heavier and has polychrome decorations with white, red, black, and orange painting, modeled-incised zoomorphic and anthropomorphic adornos [ornamentation on the rims or handles of ceramic pieces] (Fig. 3), incised motifs (Fig. 4), and some zone-incised crosshatched decorations. Barrancoid pottery developed around AD 650 in the southern West Indies and occurred concurrently with Saladoid pottery with influences from South America. Barrancoid pottery has modeled-incised handles, and anthropomorphic and zoomorphic hand, feet, and face adornos.

At the same time as the Saladoid, Huecoid ceramics developed in the northern West Indies

around 800 BC and lasted through AD 200. Researchers believe this pottery has influences from Central America. These ceramics are decorated with curvilinear-incised zones with punctuates and cross-hatching. Huecoid ceramics were not painted, but some included white or red paint or slip rubbed into the incised or hatched patterning. Some pottery was adorned with zoomorphic adornos (Fig. 5) and/or shaped into aquatic animal forms.

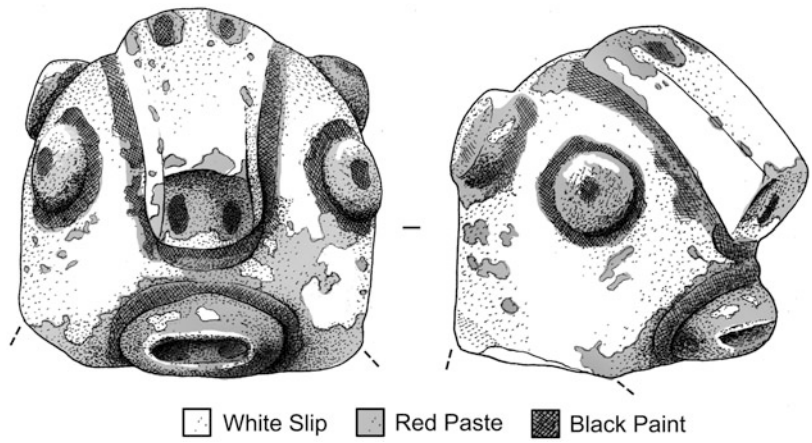


Ceramics in the West Indies, Fig. 2 Zone-incised cross-hatching decoration on bowl (Drawn by Eric Carlson after Fig. 61 in Hardy, Meredith Devereaux, Saladoid Economy and Complexity on the Arawakan Frontier. Unpublished Ph.D. dissertation, Department of Anthropology, Florida State University. 2008)

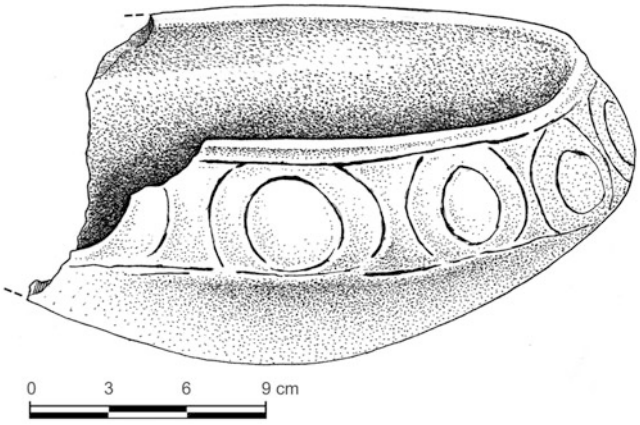
The Casimiroid is a preceramic period that developed independently on Cuba and Hispaniola starting around 4000 BC. Casimiroid pottery developed on Hispaniola during the Courian subperiod between 2630 BC and AD 240 on Hispaniola.

During the post-Saladoid period, a differentiation in pottery series between the Greater Antilles and northern West Indies and the Lesser Antilles appears. In the Greater Antilles, the Ostinoid series developed from the Saladoid or Casimiroid periods in Cuba, Hispaniola, Jamaica, Puerto Rico, and the Bahamas around AD 600 and continued until AD 1500. The Ostinoid series is further broken into regional and temporal variations based on pottery decoration and forms with variants often occurring simultaneously on the same island. The Troumassoid series developed in the Lesser Antilles during the same period and is broken into temporal subseries.

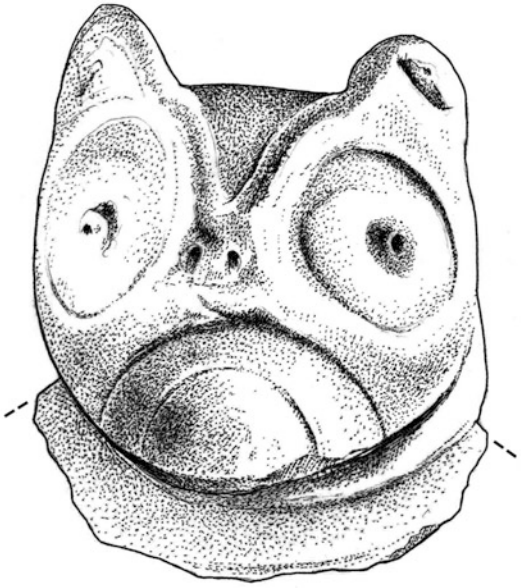
In the Greater Antilles, the Elena Ostinoid dates from around AD 600 to AD 1200 and occurs in eastern Puerto Rico and the Virgin Islands. This pottery series is marked by a reduction in decorative elaboration and overall craftsmanship from the earlier Saladoid but appears to be better suited for utilitarian uses. During the first half of the period, red-painted and plain varieties dominate with smaller numbers of black, negative, and smudged decorations. Biomorphic modeled, strap, lug, and tubular handles are also found. The second half of the period shows a return to modeled and incised



Ceramics in the West Indies, Fig. 3 Transformational adorno from Barbados (Drawn by Eric Carlson after Fig. 4 in Waldron, Lawrence. Geographic Distributions of Zoomorphic Motifs in Saladoid Ceramics. *Caribbean Connections*. 2011. http://fieldresearchcentre.weebly.com/uploads/1/8/0/7/18079819/waldron_2011.pdf)



Ceramics in the West Indies, Fig. 4 Incised and carinated bowl (Drawn by Eric Carlson after Fig. 61 in Hardy, Meredith Devereaux. Saladoid Economy and Complexity on the Arawakan Frontier. Unpublished Ph.D. dissertation, Department of Anthropology, Florida State University. 2008)



Ceramics in the West Indies, Fig. 5 Huecoid screech owl adorno (Drawn by Eric Carlson after Fig. 24 in Waldron, Lawrence. Geographic Distributions of Zoomorphic Motifs in Saladoid Ceramics. *Caribbean Connections*. 2011. http://fieldresearchcentre.weebly.com/uploads/1/8/0/7/18079819/waldron_2011.pdf)

decorations, zoomorphic adornment, and an almost absence of painted or slipped decorations.

The Ostionan Ostinoid dates from AD 600–1200 and has been found in western Puerto Rico as well as Jamaica, Hispaniola, and Cuba. There is also a simplification in pottery decoration and styles during the Ostionan, but many Saladoid variations are retained. Red-painted or slipped varieties survive along with looped handles and zone painting. Island variation exists with red-, pink-, or lilac-colored painting, inciting, and zoomorphic adornments.

The Meillacan Ostinoid was first defined in Hispaniola and is found in Cuba, Jamaica, and parts of the Bahamas and dates from AD 600–1500. There is debate as to whether the Meillacan Ostinoid developed in place from the Casimiroid, developed out of South American influences, or borrowed from the Ostionan Ostinoid, but there do not seem to be many Saladoid influences. The pottery almost is devoid of painting and is generally characterized by rectilinear incising that forms hatching and cross-hatching designs along with punctuates and appliques. Handles are generally straps with geometric or zoomorphic decorations.

The Chican Ostionoid dates from AD 800–1500 but is most common from AD 1200–1500. This pottery is found in the Virgin Islands, Puerto Rico, eastern and southern Hispaniola, eastern Cuba, the Bahamas, and the northern Lesser Antilles. Chican Ostinoid pottery is primarily characterized by bowls with incised shoulders with circles, triangles, parallel dashes, and lines. Painted pottery is almost absent from this series but is found at some sites. Handles include biomorphic, modeled head lugs, and adornos.

The Palmettan Ostinoid is found in the Bahamas and Turks and Caicos islands and dates from AD 600–1500. This pottery series was previously

Ceramics in the West Indies, Fig. 6 British-made blue transfer printed pearlware that dates from 1780 to 1820 (Photo by author)

thought to be unrelated to other West Indian ceramics but is now thought to be related to the Chicano Ostinoid and Meillacan Ostinoid based on similar decorations. The Palmettan Ostinoid has been divided into subseries such as Abaco Redware, Crooked Island ware, and Palmetto ware that does not necessarily correlate with specific geographical areas. There is temporal variation in these subseries with the Abaco and Crooked Island ware occurring before the Palmetto ware.

In the Lesser Antilles, the Troumassoid ceramic series follows the Saladoid series and is divided into two temporal periods: Troumassan and Suazan Troumassoid. The Troumassan Troumassoid immediately follows the Saladoid period and dates from AD 600–1000. This subseries carries forward many Saladoid characteristics, but over time, there is a trend in decreasing decorative and vessel-form complexity. In the northern Leeward Islands, the Troumassan pottery has bicolor and polychrome painting with broad-lined and curvilinear incisions. In the Windward Islands, the Troumassan Troumassoid is characterized by decreasing complexity in decoration with red, black, and white paints and curvilinear-incised lines dominating. There are many similarities to pottery from South America, including cotton spindle whorls suggestive of cotton cultivation and trade.

The Suazan Troumassoid subseries dates to AD 1000–1500 marks the end of the pre-Columbian pottery production in the Lesser Antilles. This period continues the overall post-Saladoid trend in pottery simplification with thicker walls, rough or scraped surfaces, and finger-indented rims. Utilitarian wares dominate assemblages, but finer wares do appear in smaller amounts and include polychrome and red painting, curvilinear and linear incising, and modeled anthropomorphic and zoomorphic adornments. Utilitarian vessel forms include griddle, incense burners, spindle whorls, and pestles.

The contact period between Amerindians and Europeans shows a continuation of the Ostinoid and Troumassoid series characteristics as well as

Ceramics in the West Indies, Fig. 7 Afro-Caribbean ware bowl from St. Kitts (Photo by author)

a melding of these traditions, influences from South America, and evidence of interactions with Europeans. For instance, the Cayoid pottery series in the central and southern Lesser Antilles dates from AD 1550–1650 and was thought to have formed out of the preceding Suazan Troumassoid. Recent research, however, has shown similarities to Carib pottery from the Guianas, and researchers believe the pottery has direct ties to South America. This idea blends well with Island Carib traditions that state Carib men came from South America and were in regular contact with Amerindian groups throughout the West Indies and South America. Cayoid pottery has decorations with similarities to the Polychrome Tradition of Amazonian vessel forms with decorative motifs related to the Chicoid Ostinoid of the Greater Antilles, and rough-surfaced griddle and bowls like those from the Suazan Troumassoid. A few Cayoid pottery shards found on St. Vincent have European beads embedded in the rims.

Ceramics during the historic period include the full gamut of European wares typical of the colonial period (Fig. 6). In general, the ceramics of each island reflects the national identity of the European colonizing nation. For instance, on islands like Montserrat and Nevis, the ceramics are distinctively British, but on St. Eustatius, a Dutch island that served as a major port and shopping center, the ceramics are much more diverse and include Dutch, British, French, and Spanish ceramics.

Ceramics in the West Indies, Fig. 8 Afro-Caribbean ware bowl from St. Kitts (Photo by author)

During the historic period, enslaved and freed Africans made and traded pottery called by

Ceramics in the West Indies, Fig. 9 Afro-Caribbean ware rims with iron oxide slip (Photo by author)

archaeologists Afro-Caribbean ware (Figs. 7, 8, and 9). Afro-Caribbean ware is a handmade, low-fired earthenware made by enslaved and freed Africans throughout the West Indies. First identified on Barbados in the 1960s, this pottery has become one of the most studied historic material types on the West Indies because it represents a direct connection to the slaves who made and used the pottery. Analyses have included macroscopic examination of paste characteristics, petrographic study of inclusions and construction methods, and INAA of the chemical composition. These analyses have identified a vibrant production history that hit its height during the late eighteenth and early nineteenth centuries. Researchers have examined the trade networks on Jamaica and found that pottery was likely made in certain production centers and radiated out along known travel routes. Within the Lesser Antilles, intraisland trade was extremely important, but some researchers have explored the interisland trade of the pottery. Researchers have used instrumental neutron activation analysis to examine the chemical composition of pottery shards to study this trade and found that numerous compositional groups occur throughout the islands and that some groups occur on more than one island. For instance, shards likely made on Nevis or St. Kitts occur on those islands as well as St. Eustatius and Antigua. Modern day potters continue to make similar pottery on Nevis, St. Lucia, Antigua, Jamaica, and several other islands.

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Ceramics in West Africa

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Archaeologists, anthropologists, and art historians have studied ceramics in West Africa. These studies have focused on ceramics as markers of identity, the role of ceramics in ritual practice, and the gendered nature of ceramic production. A range of technical and stylistic ceramic forms have been identified throughout West Africa that can be correlated with different historically known ethnolinguistic groups to varying degrees (Mayor, 2010). A number of long-term regional studies in West Africa are focused on filling the gaps in our knowledge of the origins and development of ceramic traditions in the region utilizing archaeological and ethnographic research. These include the Mandara Archaeological Project in Cameroon, Nigeria, and Ghana (David, 1998) and the Mission Archéologique et Ethnoarchéologique Suisse en Afrique de l'Ouest (MAESAO) in Mali (Gallay, Huysecom, & Mayor, 1998; Mayor, 2010). Both projects trace changes in ceramic technology and style. However, the numerous similarities between decorative styles and vessel forms make it difficult to delineate potting traditions based solely on aesthetics. In this entry, key aspects of the different ceramics, potting techniques, and traditions are highlighted, recognizing that this is by no means an exhaustive summary. As such, only ceramic vessels and not other objects made from fired clay will be addressed.

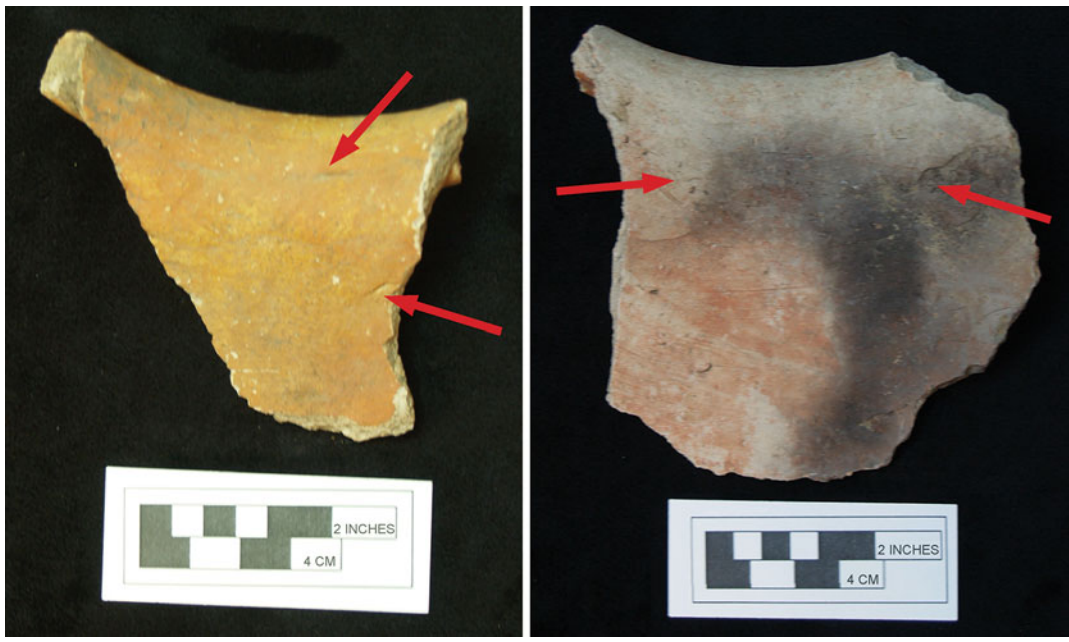
Definitions and Characteristics

West African ceramics are classified as low-fired earthenware and are typically some form of hollowware vessel serving a range of purposes. Most ceramics function as cooking, serving, and storage containers for water, medicine, oil, or grain. Ritual ceramics are also produced and may be similar in shape and design to those used for foodways. In the Gambia, restricted hollowware vessels similar to those used for storage would also serve ritual functions. These vessels would be transformed into juju (a ritual charm or amulet) through burial. Archaeological examples include pots containing stone, animal bone, and botanical remains. Ritual ceramics can also be incorporated into shrines or burials. These ceramics are often similar in form to everyday wares and can be identified by their poorer quality (Norman, 2009, p. 196). There are also specialized forms that are produced in areas of Benin and Ghana.

West African ceramics are less refined than wheel-thrown and kiln-fired wares because of the lower firing heat which in turn makes them more porous. The potter builds the vessel by hand using local clays. Clay extraction is carried out in a number of ways including surface collection, pit extraction, gallery extraction, and underwater collection (Gosselain & Smith, 2005, p. 3). Throughout most of West Africa, the local clay requires processing and tempering agents such as chaff, sand, grog (broken ceramic), or shell to survive the firing process. The vessels are created from the processed clay using a range of shaping techniques including but not limited to coiling, slab, or pound molding, molding over an existing pot (convex-form molding), or molding in a convex form. Many potters utilize a combination of these techniques, shaping the body of the pot in one way and adding the rim manufactured in another. Depending on the ability of the potter, the manufacturing technique may be evident in the final product (Figs. 1 and 2).

Once the pots are shaped and smoothed, they are left to dry until they are leather hard. At this stage, various finishing techniques may be used. Finishing techniques include slips, burnishing, smoothing, or painting the surfaces of the vessel. In addition, decorative elements are often impressed or carved into the exterior of the vessel at this time. The most common decorating technique identified throughout West Africa both archaeologically and ethnographically is roulletting. Camps-Fabrer (1966) classified a range of

Ceramics in West Africa, Fig. 1 The nineteenth-century ceramic rim and body sherd from Berefet, Gambia, with no visible evidence of coiling



Ceramics in West Africa, Fig. 2 The nineteenth-century ceramic rim and body sherds from Berefet, Gambia, exhibiting evidence of coiling manufacturing

roulette decorations based upon the tool used. These could be applied to the ceramics vessel using a braided cord, cord-wrapped stick, or natural plant material. McIntosh (1995) and Galley (1970) have expanded this list to include a greater range of cord-wrapped designs as well as impressions made using various types of shells. Various patterns have been associated with different regional areas and have demonstrated a temporal variation (Haour et al., 2010, pp. 7–9). However, ethnographic work has demonstrated that technical style (i.e., vessel construction techniques) is more closely tied to ethnic affiliation than decorative motifs (Mayor, 2010, p. 15). This is largely attributed to the fact that it is easier to mimic a design than gain access to technical knowledge which requires a period of apprenticeship. The completed pots are piled together and surrounded by fuel. This is an open-air firing process with the vessel in direct contact with the fuel source which can be wood, straw, or palm leaves depending on what is available in the local environment.

Origins and Ceramic Traditions

Ceramic production in Africa is believed to have originated in the Central and Eastern Sahara as well as the Nile Valley between the late tenth and early ninth millennium BC (Jesse, 2003, pp. 40–42), and the technology expanded from the east, including the modern nation of Sudan. The earliest known West African ceramics were found at Mouche at Ounjougou in Mali. These have been dated to the late tenth millennium BC using C14 and OSL techniques (Huysecom et al., 2009, pp. 906, 907). This places the beginning of ceramic production in sub-Saharan Africa as early as production in the Nile Valley. Three ceramics were recovered dating to this period at Mouche. Vessel form could only be determined from one sherd which is a rounded bowl. A second sherd has an impressed decoration (Huysecom et al., 2009 pp. 910). These sherds are clear antecedents to the variety of ceramics manufactured throughout sub-Sahara into the present.

There are distinct differences that have been observed in the archaeological record that persist today between ceramic traditions in the northern Sahel-Sudanic and southern savanna-forest regions. This historical division is first observed in ceramics from Korounkorokalé (Mali) dating between 4240 and 3800 BC. These vessels are described as an offshoot of the northern traditions found in the inland Niger Delta including Djenné-Djeno. It is not until the third millennium AD that distinct ceramic traditions have been identified by archaeologists in Mali that are distinguishable from neighboring areas by both aesthetic and technical style (McIntosh, 1995, pp. 130–215). The phase I ceramics identified at Djenné-Djeno are semi-refined open and closed hollow vessels with a high prevalence of twine impressions and grog-tempered wares (McIntosh, 1995, p. 212). Those from the southern savanna and forest zones are characterized by everted rims and course grog-tempered paste and they are decorated using relief or grooved motifs (Frank, 1998, p. 20).

Production Organization

The primary producers of ceramic vessels in West Africa are overwhelmingly women. Male potters are rare but can be found among the Mossi (Ivory Coast, Burkina Faso, and Nigeria) and Hausa (Nigeria) to name a few examples. While women create ceramic vessels, they are often prohibited from producing other objects from clay. This is seen among the Asante whereby women are not allowed to create pipes or anthropomorphic figures (Rattray, 1927, p. 301). Potters are present in nearly all ethnic groups in the region, with a few exceptions (e.g., the Bozo). In those societies where craft castes are present, potting is restricted to women of particular lineages. They can be members of these lineages either through birth or marriage. For several groups including the Mande, Dogan, Senufo, Mafa, and Dowayo, only the wives of blacksmiths can be potters (Vincentelli, 2004, p. 51). Fulani potters also marry blacksmiths, but they can also be the wives of weavers,

leatherworkers, or woodcarvers (Mayor, 2010, p. 9). For many groups, a potter is viewed as a female blacksmith, and a Dogan legend suggests that pottery originated in the smithy (Barley, 1994, p. 53).

Mande potters in the Kadiolo region of Mali are tied to griot rather than blacksmith lineages. Frank (1993) has convincingly argued that this anomaly to Mande tradition is the result of these women's ancestry as slaves in the region. Precautions are taken in many of these societies to restrict craft production to the proper lineage. For example, the Senufo will not train a potter until after marriage, whereas many Mande women will marry men outside of their village in order to ensure that they are blacksmiths.

In addition to lineage-based restrictions, other taboos surround ceramic manufacture. Much of this is tied to beliefs about the nature of the earth. In many societies, the earth is considered female and a connection is made between various forms of production including potting to fertility and reproduction. These taboos can be specific to a particular vessel that is made, the time when potting can take place or who is able to pot at certain times. Among the Yoruba, red is not worn when near the clay pits because of its association with menstruation. Age restrictions are present in different societies as well. For the Yoruba, postmenopausal women cannot make sieves which are used in grain processing. Kelly and Norman (2006) have noted that production of specific ceramic forms is restricted to different potters in southern Benin. Older Gbe-speaking women in this area control the local industry, and they are the only ones able to produce ritual ceramics. The Bamana presents a further example. For them, girls are not deemed full-fledged potters until they go through an excision ritual. During this, their virginity is checked, and those who do not pass are banned from potting (Herbert, 1993, p. 209).

Ceramic production has declined significantly in West Africa beginning in the mid-twentieth century. This has been correlated to the widespread availability of low-cost metal and enamel wares. While the production of everyday utilitarian vessels is declining, specialized wares continue to be manufactured. In Benin, the production of ritual vessels continues, though other forms have fallen into decline. An extreme example of this loss of potting traditions is the situation in the Gambia where only a small number of villages have women who continue to produce ceramics (Vincentelli, 2004, pp. 53–54). These include villages in the Foni and Wuuli districts. Regional production is evident in the physical nature of these ceramics despite the fact that the potters are Mande. Both traditions utilize grog temper. The Foni wares are not burnished and have red- to orange-painted decorations. In contrast, those produced in upcountry are highly burnished and have white-painted designs (Fig. 3). The vessels produced by all potters are limited to closed pots, incense burners, large water storage containers, and steamers.

Conclusion and Observations

West African ceramic production is a long-standing practice. As a material class, these are distinguished from imported wares by their coarse texture and lack of glaze. These ceramics were and continue to be a craft or cottage industry rather than being mass produced. Because of the localized production, the ways in which the pots are created as well as decorated at times can signal ethnic affiliations. This correlation has been used to understand past migrations and settlement throughout the region. Ethnographic research has highlighted the engendered nature of production. The majority of West Africans who have in the past and continue to produce ceramic pots are women. The abandonment of ceramic production in different areas of West Africa is primarily the result of cheap and readily available alternatives including metal and plastic wares. Because of this decline, ceramics that are produced today are highly specialized for either domestic or ritual use.

Ceramics in West Africa, Fig. 3 Ceramics currently available for sale in the Gambia in 2008

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Ceramics: Maya Pottery

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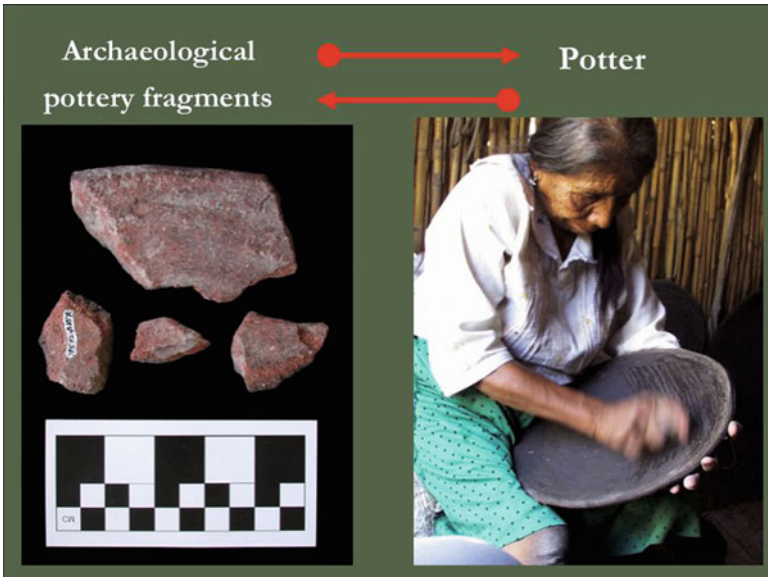
A social analysis of pottery investigates how potters translated into clay the social values and representations of people's lives, simultaneously considering how these objects defined their being in the world (Fig. 1). After decades of studying Maya pottery as a chronological marker of site interactions, ceramicists in the Maya region are researching the life histories of pots and potters under new theoretical paradigms and techniques (Jackson, 2009; LeCount, 2010; López Varela & Dore, 2005; Luke, 2012). Maya pottery studies are ready to begin this new journey, after a long history of using a methodological approach known as the type-variety system. Maya pottery is the result of a high level of technological expertise and knowledge. Each pot was made and used for the daily life activities of people we now called "the Maya."

Analytical Approaches to the Study of Maya Pottery

Since the beginning of the twentieth century, archaeologists have studied pottery mostly to order archaeological remains in time and space so they can interpret past cultures. There are many reasons why pottery became the ideal data to reconstruct culture. Basically, pottery fragments can be arranged in a sequence of formal characteristics and styles called attributes. By determining the location of the pottery type in a stratigraphic column, the archaeologist dates a particular time and is able to produce a ceramic sequence. These goals in archaeological research conformed to cultural relativism, a theoretical and methodological approach established by Franz Boas, concerned with documenting culture-historical sequences and influences (Hodder, 2004, p. 23).

Deriving from these goals, the type-variety system was introduced in 1960, as a systematic procedure to describe Maya pottery (Smith, Willey, & Gifford, 1960). To establish a type, the analyst takes into consideration decorative techniques and vessel form. When the analyst notes differences in ware, decorative techniques, vessel form, design, or temper, a variety of a type is established. The ware describes the paste composition (texture, temper, hardness, porosity, and color) and surface finish. When several types share the same ware, they form a ceramic group. Simultaneously, all of the known attributes are indicative of a particular class of pottery produced during a specific time interval known as the ceramic complex (Sabloff & Smith, 1969, p. 77). By 1965, use of the "system," as colloquially referred to by its users, had created analytical and methodological problems. These were discussed during the Maya Ceramics Conference, held in Guatemala City (Willey, Adams, & Culbert, 1967). The strengths and weaknesses of the type-variety system, assessed mostly in qualitative terms, continue to be discussed and debated (Adams, 2008; Aimers, 2013; Culbert & Rands, 2007).

In 1969, Sabloff and Smith introduced a format to present the type descriptions of the



Ceramics: Maya Pottery, Fig. 1 Learning how potters translated into clay the social values and representations of people's lives is a challenge for pottery analysis (Illustration by Sandra L. López Varela)

Seibal pottery, used by archaeologists working in the southwest of the United States (Colton & Hargrave, 1937). For many analysts, the format, later extended in the Seibal monograph (Sabloff, 1975), introduced a comparative framework for understanding pottery network distributions and extended the possibility to recognize new pottery attributes, leading to the establishment of new categories (e.g., Adams, 1971; Kosakowsky, 1987; López Varela, 1989; Smith & Gifford, 1966; Valdez, 1987; Varela Torrecilla, 1998). Each resulting monograph, presenting the description of the pottery and chronology, is to Maya pottery analysis the equivalent of any taxonomy book to biology. The analyst learns the taxa by reading the descriptions of the pottery and looking at the illustrations reported in the monograph.

In the field, the "system" may only be qualified as invaluable to the ceramic analyst, studying hundreds of bagged pottery fragments to answer common questions raised by archaeologists regarding the time framework of every excavated context. The type-variety system is used as a quick and reliable method to compare and date pottery (Smith, 1979). The analyst is able to date any context, "good, fast, and cheap," with the type-variety system. The type-variety system has become a common artificial language for Maya ceramicists. The system provides artificial identities necessary for archaeologists to state what something is and what it is not; otherwise, there would be no process of communication to interpret their results. However, to study the richness in form and dexterity in the making of every Maya vessel, multiple approaches are needed. The type-variety system is the essential first step.

Early Uses of Science and Technology in Maya Pottery Studies

After World War II, the North American school of archaeology adopted the scientific method (Binford, 1962). This new way of doing science involved the testing of hypotheses, using technology and rigorous methods, such as statistics, to produce a law, model, or theory adequately accounting for cultural phenomena. Archaeology was concerned with objectivity, systematization, and the need to provide explanations of the observed phenomena.

The search for objectivity raised criticism of the failures of taxonomic systems to appraise the meaning of pottery (e.g., Dunnell, 1971). Krieger (1944, p. 272) suggested objectivity could be reached based on demonstrable historical factors, not only on "the inclinations of the analyst or the niceties of descriptive orderliness." Most of the debates were trapped in an endless circular

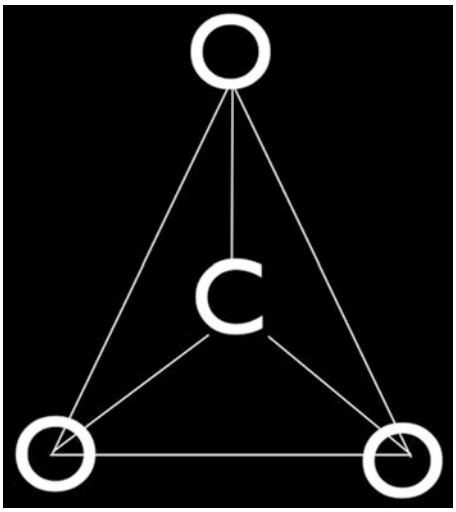
discussion of subjectivity versus objectivity, determining how many conditions are necessary for membership in a class.

In following this scientific trend, quantitative methods to approach the chronological ordering and distribution of pottery were introduced in Maya pottery studies. Statistical methods, such as seriation, were used to learn about the inherent space and time dimensionalities of Maya pottery (Henderson & Beaudry-Corbett, 1993; López Varela, 1989; Vallo, 2002). Seriation is a relative dating technique considering the chronological ordering of a group of artifacts or assemblages, where the most similar ones are placed adjacent to each other in the series. The seriation method, however, is not an objective means for finding the life span of artifacts, as it orders the number of pottery attributes defined by the type-variety system.

Interest in understanding the craft specialization and technology of Maya pottery required the integration of mineralogical analysis (Ford & Rose 1995; Iceland & Goldberg, 1999; Jones, 1986). Archaeologists use petrography to identify rocks in thin sections precisely, aided by a microscope and careful mapping of rock units. Petrography is primarily concerned with the systematic classification and precise identification of rocks in thin sections, aided by a microscope and careful mapping of rock units. Instrumental techniques, mainly INAA (instrumental neutron activation analysis) and XRF (X-ray diffraction), have been used to investigate the provenience and to determine the concentration of trace and major chemical elements in Maya pottery (Rice, 1976).

The use of instrumental techniques implicitly assumes the results provide us with information about Maya pottery production and distribution. Archaeologists have accepted the resulting data, under the strength of "scientific authority," without being able to interpret the nature of the data adequately or the problems regarding the analytical sensitivity, precision, and accuracy of physical or chemical techniques, including the preferential use of some laboratories (Bishop, Canouts, Crown, & De Atley, 1990). Customarily, instrumental techniques are giving us information about the provenance of 13 or 19 chemical elements in "pure" form (Kosakowsky, Estrada Belli, & Neff, 1999; Neff, Bove, Robinson, & Arroyo, 1994; Neff, Cogswell, Kosakowsky, Estrada Belli & Bove, 1999). The given set is integrated by some of the most abundant chemical elements on earth. Absent from INAA results is silicium (Si, silicon in English) and aluminum (Al), the main components of silicate minerals and aluminum oxides, constituting the basis of pottery clay.

The limitations in the use of instrumental techniques is not the failure of a particular laboratory and analysts, but, rather, the limitations of solving an archaeological problem. There is a substantial analytical difference between learning about the technology of pottery making and identifying the chemical elements in a pot. Contrary to Neff's (2005, p. 210) position, if we were to guide these studies from an anthropological perspective, it would matter if we used chemical or mineralogical approaches to source determination or how many chemical elements of the periodic table need to be measured to learn about the making of pottery. When we look through the microscope, we are observing a substance containing no social information. The analyst considers a chemical compound, such as carbonates, as a triangular structure with a carbon at its center and an oxygen atom on each corner, bearing distinctive density or coloration qualities, except social information (Fig. 2). When the archaeologist wants to extract social meaning from what he has observed under the microscope, this corollary is unintelligible to the chemist. Chemical phenomena occupy a realm largely distinct from social phenomena (Latour, Woolgar, & Salk, 1986, p. 23). In opposition, the construction of knowledge in archaeology reads science as culture. Material sciences are mostly applied to provide precise physical and chemical properties from which an object is constituted to learn about culture or human behavior (Jones, 2002, p. 66).



Ceramics: Maya Pottery, Fig. 2 Chemical elements and minerals contain no social information. Carbonates identify as a triangular structure with a carbon at its center and an oxygen atom on each corner, bearing distinctive density or coloration qualities, except social information (Illustration by Sandra L. López Varela)

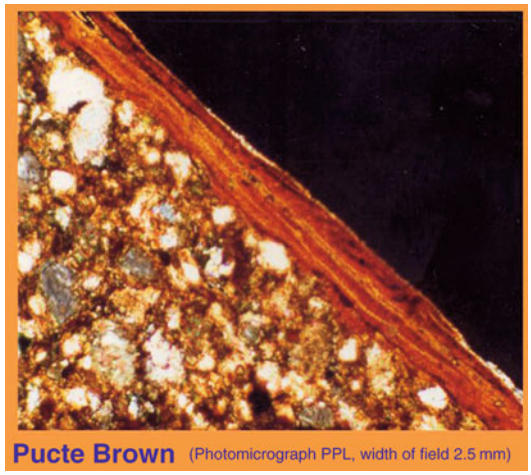
New Routes for the Use of Science and Technology in Maya Pottery Studies

Instrumental techniques are being used to learn about Maya pottery, as a complex mixture of raw materials often from disparate sources with clay and non-clay minerals mixed together in different forms and varying ways to produce a pottery fabric. These increasingly available studies are using technology to learn about the uses of pottery and the choices potters made to produce a pot. These studies are providing the field of Maya pottery with insightful analytical results (García-Heras et al., 2006; Goodall, Hall, Viel & Fredericks, 2009; Fanjat et al., 2013; López Varela, 2005a; Meanwell, Paris, Cruz Alvarado, & Peraza Lope, 2013).

The Maya region is a vast terrain with varying geologies and topographies providing the raw materials for many different recipes to make pots. These raw materials were washed or levigated (made smooth), and non-plastic temper (to create hardness and elasticity) of certain grain sizes was added or mixed with other clays. Maya potters had a thorough knowledge of the different properties of the available natural resources, including their thermal behavior, to make a functional vessel. Learning about the physical and chemical properties of the clay bodies is important to determine the suitability of a vessel for cooking or storing different kinds of products (López Varela, 2005a). A wide range of techniques deriving from the physical, chemical, and natural sciences is helping archaeologists identify how potters chose to select raw materials and how natural resources were used to make pots to support numerous daily life activities, for everything from cuisine preferences to cave rituals.

Technological and characterization studies provide insightful information about the function of a vessel. Throughout the history of humankind, people have used objects differently from their intended function. When a cooking jar was placed in a burial site or a cave, it extended its meaning beyond the domestic realm into the underworld. With this knowledge, archaeologists may distinguish if a vessel was used for its intended function or if it was used to signify, empower, embody, and/or engender the living spaces of the Maya. Identifying the residues trapped in Maya pots reveal how these were used. Ultra-performance liquid chromatography (UPLC)/MS-MS Analysis has already detected the presence of *capsicum* in excavated Formative pots from Chiapa de Corzo (Powis et al., 2013). This same technique has yielded valuable information about the consumption of cacao through its identified residues in spouted vessels from Colha (Hurst, Tarka, Powis, Valdez, & Hester, 2002). Molecular archaeology, a developing field, has already been used to determine blood residues in Maya pots from Copán (Matheson, Hall, & Viel, 2009).

Raman spectroscopy is commonly used to investigate the mineralogical composition of materials and to investigate the making of paints. In the Maya region, Raman spectroscopy has provided information regarding the surface treatment of vessels from Copán but also, about the firing process of Maya pots (Goodall et al., 2009).



Ceramics: Maya Pottery, Fig. 3 Microprobe analysis of Pucte Brown pottery (Micrographs by Daszkiewicz et al., 1999, illustration prepared by Sandra L. López Varela)

Basically, this study has successfully identified paint mixtures for each color applied to different ceramic types and estimated the firing techniques through the different phases of iron oxide (Goodall et al., 2009, p. 108). Microprobe analysis is another technique used to determine how Maya potters treated pottery surfaces. At K'axob, potters selected vessels with a calcareous matrix, with rhombohedric carbonates of coarse silt and fine sand fraction, to paint their surfaces. This fine textured fabric yields relatively flat surfaces, easily smoothed with a pebble. The use of microprobe analysis revealed potters used brushes to facilitate the application of several slip coatings (Daszkiewicz, Schneider, & Bobryk, 1999). Preparing the surfaces to display the images on a Saxche Orange Polychrome vessel, required the potter to apply a fine layer of engobe before adding an iron-rich red slip (Fig. 3). Engobe is liquid clay used to decorate a ceramic piece before it has been fired and usually applied before the piece has dried. The black color of Actuncan Orange Polychrome contains both manganese and iron, contrasting with the iron-rich red slip. Black paint on Ixcanrio Orange Polychrome and Saxche Orange Polychrome fragments contained manganese. By controlling the original oxidizing and reducing atmosphere, the potter achieved both a red and a black color. Additionally, LA-ICP-MS analysis of the chemical composition of the exterior slips, and red and black pigments of vessels originating from the central Petén lakes region of Guatemala suggest the Itza and Kowoj used different pigments for exterior slips and decorative motifs (Cecil & Neff, 2005).

In dating Maya pottery with instrumental techniques, thermoluminescence has not been successful for dating samples with a sedimentary origin (Wagner, Haberman, & Wagner, 1999). Additionally, archaeointensity determinations on Maya incense burners from Palenque, supported by Mössbauer spectroscopy, have estimated their firing temperatures (Fanjat et al., 2013). However, limited comparative data restricts the possibility of establishing a trend of intensity variations in Mesoamerica (Fanjat et al., p. 168).

The availability of portable and noninvasive technologies, such as pXRF spectrometers, is about to change the ways we study Maya pottery in the field. The ability to collect compositional data rapidly from highly specific locations on individual artifacts and its nondestructive capacity, pXRF, is aiding investigations along the Motagua Valley in Guatemala and the Naco Valley and Cacaulapa Valley in Honduras (McCormick & Wells, 2013).

A Social Analysis of the Making of Maya Pottery

A social approach to the study of Maya pottery is concerned about investigating how material culture expresses the ways we conceptualize the relationships between others and ourselves, and between us as ceramicists and the Maya in the past. In building ceramic sequences through the type-variety system, archaeologists have struggled to define the pottery, characterizing the Terminal Classic and the subsequent post-Classic period. Despite the observed persistence of pottery forms and wares through time, innovation and continuity have to be accommodated to the theories suggesting a foreign population took over Maya Lowlands sites, putting an end to

Maya culture around AD 800 (Adams, 1971; Sabloff, 1973; Sabloff & Willey, 1967). Over the course of new excavations, we have learned fine paste pottery, a considered trait of such population, was not exclusively made during the Terminal Classic; alternative regions were producing the pottery, even during Formative times; and the pottery did not always display militaristic images (Bishop & Rands, 1982; Foias & Bishop, 2005; Lopiparo, Joyce, & Hendon, 2005; López Varela, 2005b; Rands, 1987). Instead of searching for answers as to why new forms were introduced at a time of political turmoil and environmental change, analysts are concerned about fitting innovation and continuity in pottery making as exceptions to the beginning-end cycle ceramic complexes are forced to express. Ceramic sequences are references for the archaeologist to measure time. Classifications are distant from the ways Maya peoples in the past constructed time and experienced meaningful times. These sequences have constructed "Maya" time following a plot (Hodder, 1995, p. 164), having a beginning (Early Classic period), a climax (Late Classic period), and an end (Terminal Classic period). In other words, this literary process has governed the ways analysts analyze pottery data.

Increasingly, archaeologists in the Maya region are becoming interested in learning how social values are communicated through different kinds of objects and their uses (Jackson, 2009; LeCount, 2010; López Varela & Dore, 2005; Luke, 2012). In approaching the ways people have used objects or natural elements for daily life activities (Meskell & Preucel, 2004), there is a genuine interest in learning about how individuals in a society communicate their particular values through objects and natural elements (Buchli, 2004; Hodder, 2004; Hoffman & Dobres, 1999; Pfaffenberger, 1999). At the Institute of Archaeology at Belmopan, there is a distinctive piece of pottery, an orange, nonglazed piece, recovered from Actun Chanona, a cave located at the base of the Sibun Gorge in Belize. This lion effigy bears a remarkable resemblance to those found in the Lion's Courtyard of the Alhambra in Granada, Spain. These lions conveyed the Quranic and Biblical images of paradise, a garden associated with four rivers, sprouting from the lions' mouth. All of these elements – water, plant fertility, directionality, and the transition of humans into a paradisiacal world – were shared concepts with the Maya. Meaning does not reside in the object itself or in its immediate surroundings, but in the way we make sense of the object. The social embedded in material culture communicates its materiality, but only if we are familiar with the meaning objects intend to convey. Within this sense of materiality and agency, it is essential to recognize both elements, the social and the natural, are intertwined, both constructing individuals and the space they live in. Learning about the "social life of things" is a theoretical approach contributing to an understanding of the spatiality of objects, to the ways people organize living spaces and how these objects define their being in the world (Tuan, 1977; Low & Lawrence-Zúñiga, 2003).

The social analysis approach favors the use of material sciences to learn about the physical and chemical characteristics of the object. Analytical techniques address the influence of the chemical and physical properties in the selection of raw materials and preparation of the clay body to achieve specific technological and functional properties. Reconstructing the step-by-step process of a given technology requires a set of interpretative questions surrounding the object of production, examining the data with material science analyses and experimentation. The social analysis of Maya pottery has incorporated the *chaîne opératoire* or operational sequence as central to the study of technologies (López Varela, McAnany, & Berry, 2001). The intrinsic hermeneutics of the operational sequence guides the investigation to reveal the social diversity of humankind by approaching the choices made all the way through it. A social approach to the analysis of Maya pottery, therefore, questions if the ratios of raw materials really influence the physical and chemical properties of the body or if there are other reasons guiding their specific use.

In fact, the concern of using instrumental techniques to define human behavior originates from

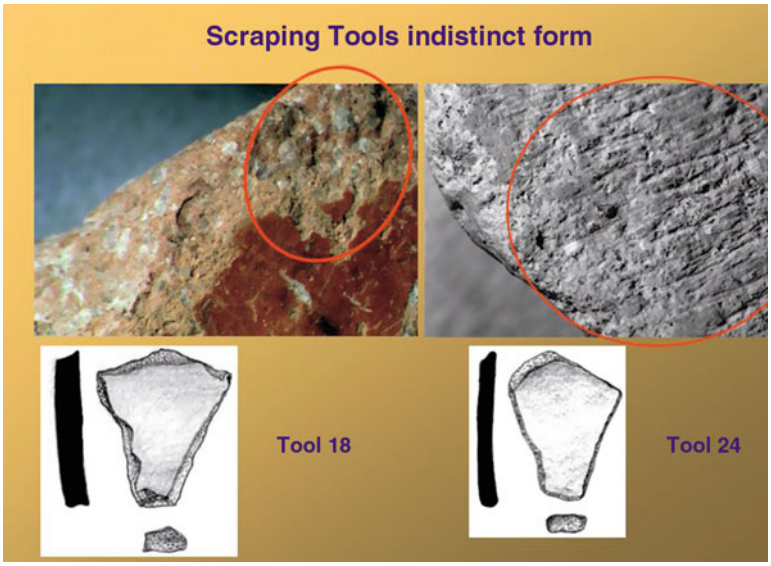
analysts doing ethnoarchaeology (Arnold, 1971, 2005). Ethnoarchaeological studies have been crucial in learning about pottery production (Arnold, 1971, 1978, 1991; Deal, 1983, 1998), despite the making of Maya pottery in the past may not be compared easily with a modern context. Indirectly, ethnoarchaeological studies as a comparative procedure to learn about the past from the present suggests people and their social values, concepts, representations, and symbols have remained unchanged (Hodder, 1982, p. 16) throughout their living of historic events. The social logic of our actions, our being in the world, indeed is embedded in history and tradition, so the detachment with the past is not absolute either. However, assuming people can live unaffected for 500 hundred years of historic events entails some naïveté (Thomas, 1996). In the future, ethnoarchaeological studies could dedicate its efforts to address the social changes incited by economic development in the Maya region (Arnold, 2008). Development policies are becoming powerful erasers of social memory and traditions through infrastructure building and welfare policies inviting potters to change the technology of pottery making and restricting the availability of natural resources.

Identifying Maya Potters in the Pots Left Behind

Archaeological research has provided further evidence of pottery making and tools (López Varela et al., 2001; López Varela, van Gijn & Jacobs, 2002). Already, analysts have identified different kinds of firing features, ranging from open hearths to double-chamber kilns (López Varela et al., 2001; Lopiparo et al., 2005; Urban & Schortman, 2004). The seminal work of Anna O. Shepard (1956, 1964) stated the relevance of investigating the technological character of Maya pottery (e.g., Angelini, 1998; Daszkiewicz et al., 1999; López Varela et al., 2002). Results deriving from these studies describe the sequence of steps, transforming natural resources into meaningful and functional objects. The chaîne opératoire (operational sequence) (Leroi-Gourhan, 1943–1945), as an analytical concept, leads to an investigation of the decisions made by the producer, in the use of natural resources to make a particular form. The decisions made by Maya potters encountered recognition in the archaeological record (López Varela et al., 2002). These decisions related to their selection of tools for the making of Late Classic vessels. Basically, potters chose to recycle broken pieces of pottery to make their tools for smoothing, scraping, incising, polishing, and boring. To make ceramic fragments suitable as tools, the edges need to be shaped; otherwise, it would be difficult to hold the piece with the fingers to perform a smoothing or scraping activity. Also, potters worked the edges of the sherds to create particular geometric forms and sizes. Selecting the shape of the pottery tool represents another choice to determine the effectiveness and performance of these implements. In the case of small tools, the angles allow reaching the joints quite easily, facilitating shaping, and retouching of the vessel (López Varela et al., 2002). These shapes adapted to the pottery grammar of simple clean curvatures and preferable angles characteristic of the Late Classic vessel repertoire (Fig. 4).

Not all pottery fragments made useful tools. Potters intentionally selected broken pieces of pottery, considering the characteristics of the fabric over hardness. Still, potters needed tools to perform a particular task. Fragments were selected considering the texture properties of the fabric and the adhesive bond power of particles, as these affect resistance to abrasion (Fig. 5). Tools used for scraping, characterized by a fabric containing angular, coarse, crystalline calcite, and rare grains of quartz, facilitated its use in such activity. Most tools were made from jars with a high frequency distribution. Broken pieces of jars or bowls could be recycled to fabricate the necessary tool fairly quickly, according to our experimental studies (López Varela et al., 2002). Consequently, cost was a factor in the making of Maya pottery.

The chemical and physical properties of the natural resources condition not only form and function but also the objectification of the social. For instance, vessels with a calcareous matrix (a substance containing calcium carbonate), according to chemical analyses, were not used

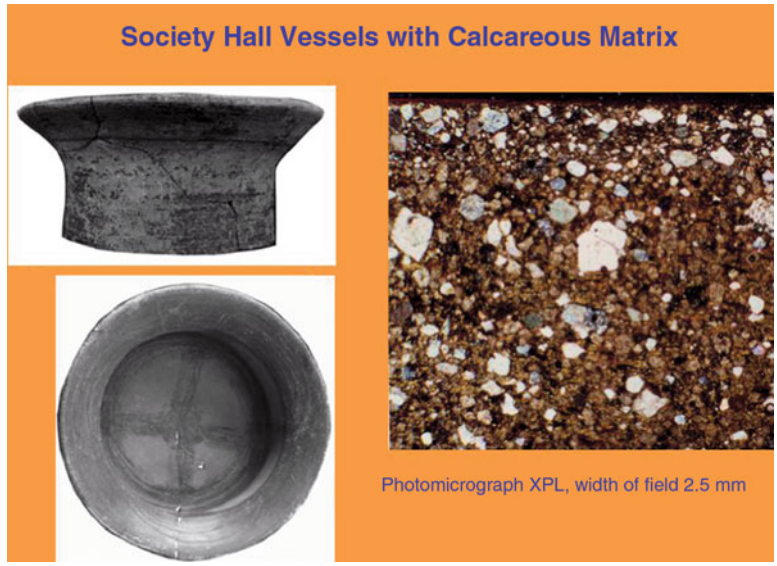


Ceramics: Maya Pottery, Fig. 4 Experimental use of a triangular tool (Photographs by Eric Mulder. Illustration by Sandra L. López Varela)

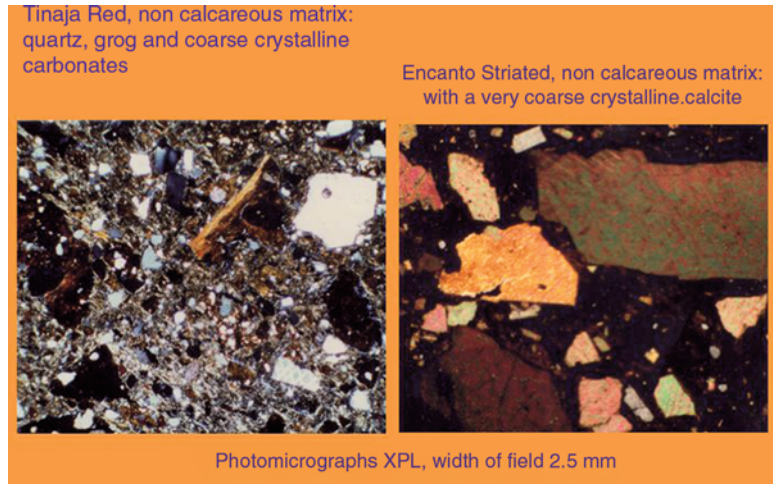
Ceramics: Maya Pottery, Fig. 5 Examples of scraping pottery tools (Photographs by Annelou van Gijn. Illustration by Sandra L. López Varela)

in cooking or in any other activity involving their use in a fire atmosphere. Most pots with a calcareous matrix exhibited appliqués, slip clay, or paint, such as Hillbank Red or Saxche Orange Polychrome. On the contrary, vessels with a noncalcareous matrix and coarse crystalline calcite, added as temper, allowed their exposure to fire (Daszkiewicz et al., 1999). Most striated jars from the Formative to the post-Classic period have a non-calcareous matrix. We learned potters changed their recipes to make pots, as jars of the Encanto Striated type contain aggregates of grog and clay in its noncalcareous matrix. Adding grog represents another choice the potter had to make either because it was necessary to recycle pottery against the lack of resources or the need for experimentation. There is evidence of the making of new recipes to make jars for post-Classic times, as the body shows large crushed particles of calcite causing the jars of Piste Striated to bloat (Figs. 6 and 7).

To acquire their raw materials, Maya potters did not have to move a long distance. There is evidence potters were quarrying in the surroundings of the pottery workshop found at K'axob (López Varela et al., 2001). In the surroundings of this workshop, 9 roughly rectangular blocks of fine-grained consolidated sediment share physical attributes, such as texture, with Belize Red pottery, easily recognized by its thin walls and fine-grained but gritty paste composition. Their size and shape are ideal for tumpline (a band or strap strung across the forehead or chest to support a backpack) or canoe transport. Samples of Belize Red type, originating from excavations at Barton Ramie, showed the gritty texture of Belize Red was attributable to fragments of pumice and volcanic glass and, to a lesser extent, grains of calcite (Gifford, 1976, p. 255). The analyzed sample from K'axob is characterized by a noncalcareous matrix with grains of quartz and aggregates of



Ceramics: Maya Pottery, Fig. 6 Examples of Society Hall vessels with a calcareous matrix (Photomicrographs by Daszkiewicz et al. (1999). Illustration by Sandra L. López Varela)



Ceramics: Maya Pottery, Fig. 7 Examples of vessels with a noncalcareous matrix could have withstand fire exposure (Photomicrographs by Daszkiewicz et al. (1999). Photographs and Illustration by Sandra L. López Varela)

cryptocrystalline calcite. The composition is not common in the chemically analyzed samples. The making of Belize Red shows potters accommodated the available natural resources to fulfill social demands (López Varela et al., 2001).

Maya potters received or provided stylistic and form conventions from and to a large-scale sphere of influence includes, at various times, the Peten, the Teotihuacan, the Usumacinta-Pasión regions, and the Yucatan. These pots represented individuals' thoughts and actions, such as the making of the tripodal cylinder vessel of Early Classic times. The vessel form was used as far as Teotihuacan and has appeared in numerous contexts in the Maya region (Varela Torrecilla & Braswell, 2003).

In the Maya region, social identity and power was displayed on painted vessels, such as those of the Saxche Orange Polychrome type. Most painted images are displayed on the outside surfaces of vases or the bottom of a dish.

Preserving the Knowledge of Maya Potters

In writing about the social in the making of Maya pottery, it is of concern to me the reader understands potters in the past had a thorough knowledge of physical and chemical properties. The type-variety system is a valuable tool to the study of the Maya knowledge. However, the use of analytical techniques is the most reliable avenue of research to investigate how pottery was made. The technological knowledge of Maya potters should be investigated and preserved with the use of instrumental techniques, experimental studies, and application of emerging theoretical paradigms.

The word technology could be inadequate to refer to the steps of how pottery was made in the Maya region. Reading the past in the realms of technology simply represents our ways of seeing the world of how potters expressed, materialize, and mediated social relations through the pots they made. My suggestion, now followed by other analysts, to investigate the social aspects of Maya pottery results from the long-time quest in archaeology of providing a human face to the pots and sherds that we excavate.

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Ceramics: Mimbres Pottery

Michelle Hegmon

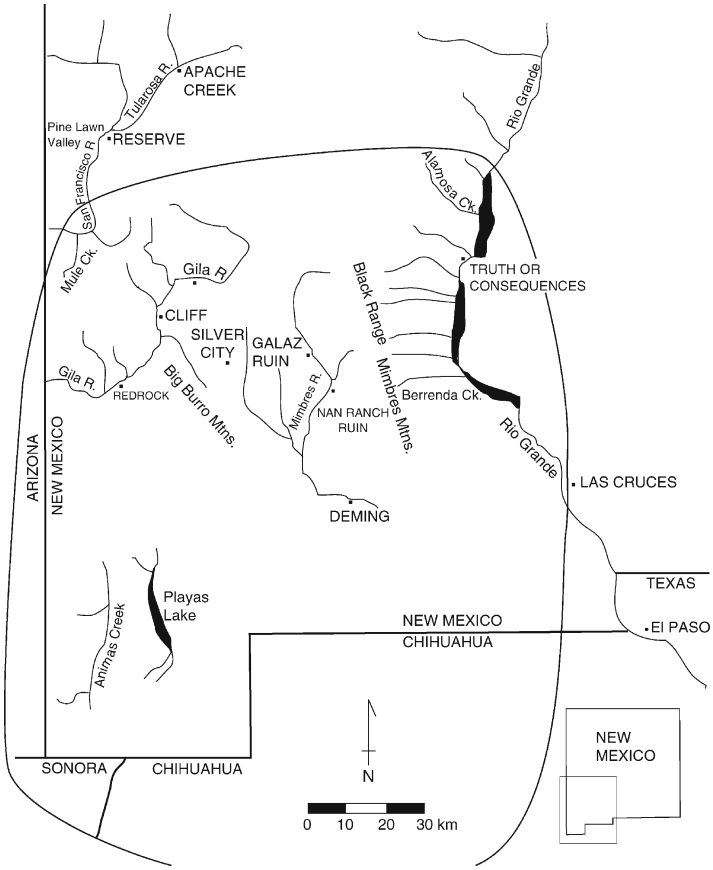
Ceramics: Mimbres Pottery, Fig. 1 Classic Mimbres Black-on-white bowl from Ronnie Pueblo (Nelson, 1999, pp. 96–97). The bowl is part of the permanent collections of the Museum of Anthropology, Arizona State University

Mimbres pottery, made primarily in southwestern New Mexico between 750 and 1150 AD, is renowned for its spectacular, often naturalistic, black-on-white designs (Fig. 1). Although painted pottery is common in the archaeological record of the North American Southwest, Mimbres pottery stands out because of its elaborate representational designs, which depict everything from the ubiquitous rabbit to scenes of everyday life and apparently mythical creatures. Because of the pottery's beauty and appeal to collectors, many Mimbres archaeological sites have been destroyed by looters searching for pottery to sell, and irreplaceable information about the past has been lost.

Mimbres, from the Spanish for "willows," is the name given to a small river in southwest New Mexico. The name came to be applied to the pottery found in archaeological sites along the river, and eventually to the people who made the pottery. However, it is important to keep in mind that these are labels applied (mostly by people of European descent) to pre-Hispanic Native Americans. We do not know what the people called themselves, although we can be sure it was *not* Mimbres. In fact, recent approaches in archaeology have attempted to decouple pottery styles and cultural identity, and have challenged the extent to which the people who made the pottery we call Mimbres were united culturally, socially, or politically. They were maize farmers living in fairly simple hamlets and villages that housed from a few households to a few hundred people. They had no writing, draft animals, or metal tools. And while their social organization was elaborate in many ways, they did not have a well-developed political hierarchy or marked social inequalities. Syntheses of Mimbres archaeology include Anyon, Gilman, and LeBlanc (1981), Hegmon (2002), Hegmon et al. (1999), LeBlanc (1983, 1989), and Nelson (1999) and a recent issue of *Archaeology Southwest* (2003). Book-length treatments of Mimbres pottery, especially the designs, include Brody (1977, 2004), Brody, Scott, and LeBlanc (1983), Brody and Swentzell (1996), Fewkes (1989), Kabotie (1982), Le Blanc (2004), Moulard (1984), and O'Bagy Davis (1995). In addition, reports on Mimbres sites include numerous pictures and analyses (e.g., Anyon & LeBlanc, 1984; Cosgrove & Cosgrove, 1932; Shafer, 2003).

Situating the Pottery in Time and Place

The Mimbres region (Fig. 2) is part of the larger Mogollon archaeological culture area, which



Ceramics: Mimbres Pottery, Fig. 2 Map showing the Mimbres region in southwest New Mexico and surrounding states

includes much of southern New Mexico and northern Chihuahua, as well as central Arizona. Mogollon pottery, made with iron-rich volcanic clays, is generally brown or red in color, while pottery made in the northern Southwest (what had been called the Anasazi area but is now more properly known as Ancestral Pueblo) is generally white or gray, sometimes with black designs. Because Mimbres pottery is black-on-white, it was initially thought to be northern in origin. However, it is now well known that Mimbres pottery is indeed a Mogollon brown ware, covered with a thin slip of white clay that provides a backdrop for the black designs. The local development of Mimbres pottery – from plain brown to red-on-brown to red-on-white and finally to black-on-white – is well understood and well dated (see especially Anyon, Gilman, & LeBlanc 1981; Scott, 1983; Shafer & Brewington, 1995; Shafer & Taylor, 1986). Because the painting style changed fairly rapidly, archaeologists are able to date the pottery quite precisely. For example, Fig. 3 illustrates a bowl with a design that extends all the way to the rim and that has straight-line hachure with framing lines thicker than the hatch lines; these are both relatively early characteristics and together they indicate that this bowl should be classified as Early Style II (ca. AD 880–920; Shafer & Brewington, 1995). Later designs (generally classified as Classic Mimbres Black-on-white or Style III, and illustrated in Figs. 1, 4, 5, 6, and 7) have various kinds of rim framing lines. Scott (1983) illustrates the stylistic changes over time, and Shafer and Brewington (1995) present a detailed microstyle chronology. Mimbres pottery includes various forms including storage and cooking jars as well as bowls. However, most of the painting and virtually all of the representational designs are found on bowls. Painted pottery was most elaborate and

Ceramics: Mimbres Pottery, Fig. 3 Style II Mimbres Black-on-white bowl from the Galaz Ruin (Anyon & LeBlanc, 1984, Plate 12a) (Photo courtesy of the Mimbres Archive [#2963)]. The bowl is part of the permanent collections of the University of Minnesota)

Ceramics: Mimbres Pottery, Fig. 4 Jackrabbit depicted on Classic Mimbres Black-on-white bowl from the Swarts Ruin (Photo courtesy of the Mimbres Archive [#2051]. The bowl is part of the permanent collections of the Peabody Museum, Harvard University)

probably most common during the Mimbres Classic Period (1000–1130 AD), and painted bowls at that time had an average volume of 2.2 l (based on data from the Galaz Ruin Anyon & LeBlanc, 1984, p. 169).

Chemical and mineralogical analyses (summarized in Gilman, Canouts, & Bishop, 1994) clearly indicate that Mimbres pottery was made in many locations and villages; it was not centrally produced. The elaborateness of the designs suggests that some may have been produced by specialists, but if this were the case they were likely part-time specialists. Recent calculations (Le Blanc, 2004) suggest that all Mimbres black-on-white vessels could have been made by just a few potters, each making only 50–100 pieces annually. While most pottery makers and painters in the pre-Hispanic Southwest were probably women, several authors have suggested that at least some of the Mimbres designs were painted by men, because they depict rituals probably controlled by men (Brody, 1977) and because the birth scenes are anatomically unusual (Hegmon & Trevathan, 1996). The issue is controversial, and a clear resolution is unlikely.

Mimbres painted pottery is found in many contexts, including in trash middens, on living floors, and in burials, across the Mimbres region. Many burials – in simple pits in middens and under house floors – were interred with a bowl placed over the skull. Most of these bowls had a small hole carefully punched out of the base (see Figs. 3 and 6); these bowls are said to have been "killed," and some have speculated that the hole allowed the deceased's spirit to escape. Many of the bowls found in burials have wear patterns that indicated they had been used before they were interred (Bray, 1982). It is possible that most individuals had a bowl that they used for eating and other purposes, and that bowl accompanied them into the grave.

The Designs

Before considering the designs and their analyses, two caveats should be noted. First, although many designs appear to be realistic, in that they accurately portray details such as the topknot on a Gambel's quail and the black tips on jackrabbit ears (Fig. 4) the corpus of designs as a

whole should not be assumed to reflect Mimbres life accurately. Rather, the pre-Hispanic artists – for various aesthetic, cultural, and social reasons – *chose* to depict certain scenes in certain ways. The designs are representations of what people believed should be portrayed on pottery, and they should be interpreted from this perspective. Second, as Brody (2003) has emphasized, the designs were painted on hemispherical surfaces (i.e., the interior of bowls) that were often placed below the user and viewer's eye level; most reproductions do not convey the designs' three-dimensional aspect or use context.

Mimbres pottery designs have been the focus of much attention, by archaeologists, art historians, and the public (Brody, 1977; Brody et al., 1983; Brody & Swentzell, 1996; Moulard, 1984), and much is known about what they depict. However, there is still a need for comprehensive quantitative analyses of the designs and their distribution, as I noted in my recent review (Hegmon, 2002). Designs with representational elements (Figs. 1, 4, 6, and 7) are less common than those that are purely geometric (Figs. 3 and 5) (221 versus 494 in the Galaz Ruin collection Anyon & LeBlanc, 1984). Most representational designs are depictions of animals native to the Mimbres region, some show scenes that include humans, and others depict apparently mythical creatures. Early Mimbres representational designs are similar to designs on pottery from the Hohokam region in southern Arizona, but by the Classic Period, the Mimbres style was unique.

Interpretations of the meanings of the designs are best made by considering their larger cultural context. Maize was a staple food in the Mimbres region, supplemented by other crops, wild plants, and meat from small animals such as rabbits, as well as occasional larger animals such as deer. In comparison, almost no maize or other plants are depicted on the pottery, and while there are many rabbit paintings (Fig. 4), there are few scenes (possibly only one in the known corpus) of rabbits being trapped or hunted. In contrast, quite a few paintings depict the hunting of larger animals, including bear and elk (Fig. 6). Taken together, these patterns support the argument that the paintings represent what people wanted to emphasize (i.e., hunting), not what they actually ate. One unpublished but widely cited analysis (LeBlanc, 1977) found that bowls depicting certain animals were associated with certain

Ceramics: Mimbres Pottery, Fig. 5 Geometric design on Classic Mimbres Black-on-white bowl from the Galaz Ruin (Anyon & LeBlanc, 1984, Plate 23E) (Photo courtesy of the Mimbres Archive [#3033]. The bowl is part of the permanent collections of the University of Minnesota)

Ceramics: Mimbres Pottery, Fig. 6 Bear hunt depicted on Classic Mimbres Black-on-white bowl from the Galaz Ruin (Anyon & LeBlanc, 1984, Plate 83E) (Photo courtesy of the Mimbres Archive [# 2902]. The bowl is part of the permanent collections of the University of Minnesota)

villages or areas, suggesting the animals were relevant more to social identity (e.g., as clan symbols) than to food.

While many of the animals depicted on the bowls would have been local to the Mimbres region, a number of exotic and probably symbolically important species are also depicted. In many cases, biologists have been able to identify particular species because the Mimbres paintings include relevant details, such as fin and beak shapes. Macaws, particularly their red feathers, have great ritual significance to contemporary Southwestern Native Americans, and a few macaw skeletons have been found in archaeological sites in the Mimbres region and elsewhere in the Southwest, suggesting that this ritual significance extends far back in time. Parrot-like birds are occasionally depicted on Mimbres bowls, and analyses of their traits indicates that most are scarlet macaws, native to the lowlands of southern Mexico and central America, more than 1,000 miles from the Mimbres region (Creel & McKusick, 1994). Similarly, analyses of the fish (and a possible whale) depicted on Mimbres pottery indicate that many are saltwater species, probably from the Gulf of California, approximately 640 km distant (Jett & Moyle, 1986). Thus it is clear that the people who painted the Mimbres designs had knowledge of distant regions, either through travel or trade and interaction.

In the past two decades, archaeologists have devoted significant attention to understanding women and gender relations in the past. Mimbres paintings give particular insights (see Hays-Gilpin, 2002) because some depict men and women engaged in various activities (almost all depictions of humans show them engaged in some activity; there are almost no simple portrait-like treatments). Some humans have clear sexual characteristics (breasts or penis), and inferences about styles of dress and body decoration associated with each sex make it possible to identify the sex or gender of many of the human figures (Munson, 2000). For example, when string aprons (Fig. 7) are depicted on individuals with clear-cut sexual characteristics, they are always associated with females; thus, string aprons

Ceramics: Mimbres Pottery, Fig. 7 Pregnant woman with parrot-like bird (possible macaw) depicted on a Classic Mimbres Black-on-white bowl from the Galaz Ruin (Anyon & LeBlanc, 1984, Plate 76F) (Photo courtesy of the Mimbres Archive [# 2845]. The bowl is part of the permanent collections of the University of Minnesota)

are interpreted as good indicators of gender (i.e., women). Drawing on this and similar analyses, Munson was able to conclude that there was a gendered division of labor in Mimbres society (men are more often associated with hunting, women with child care). However, there is at least one famous scene of a pregnant woman (seemingly triumphant) carrying a hunted antelope; this image graces the cover of a milestone volume on gender and archaeology (Gero & Conkey, 1991). Furthermore, although more men than women are depicted engaged in apparently ceremonial activities, women are consistently shown handling ritually important parrot-like birds (often macaws) (see Fig. 7).

Contemporary artists often state that their art conveys meanings that cannot be put into words, and it is likely that the same applies to art of the past. It is also likely that Mimbres pottery painting – done by perhaps hundreds of artists over approximately four centuries – conveys a range of meanings. However, researchers have gained some insights into the general range of meanings associated with the pottery. Because the bowls are often found in burials, and some

depict scenes from what appears to be the Puebloan World of the Dead, Brody and Swentzell suggest the images refer to "the unity of man and the cosmos, the living and the dead, and of the structures of harmony" (1996, p. 38). Moulard (1984) similarly concluded that the designs symbolize transformations, such as from life to death or childhood to maturity.

Collections

Mimbres pottery – particularly pieces with representational designs – has long had great appeal to collectors. The result has been the destruction and desecration of Mimbres sites. The large site of Old Town is well known for looking like a mine field because it is so full of large holes, many made by backhoes and bulldozers. Galaz Ruin (Anyon & LeBlanc, 1984), one of the largest Mimbres villages, no longer exists; it was completely removed by bulldozing. Much of this activity is illegal (i.e., it is illegal to disturb archaeological remains on public land, and it is illegal to disturb human remains even on private land), but law enforcement cannot always keep pace (Turnbow, 2001). In an attempt to stop the destruction and preserve some of what remained of Mimbres archaeology, Steven LeBlanc formed the Mimbres Foundation in the 1970s, and today the Archaeological Conservancy undertakes similar activities on a much wider scale (Blanc Le, 2003). Also, many responsible authors are today refusing to publish images of looted bowls so as not to increase their value (e.g., the second edition of Brody's *Mimbres Painted Pottery* 2004), a strategy in line with the ethnical guidelines of the Society for American Archaeology. Thus the situation is improving, though destruction continues (Turnbow, 2001).

The problem with collections is not simply private ownership of the remains of past Native American cultures. A more serious issue is that the demand for collections, and the high prices paid for Mimbres pottery on the art market, encourage the illegal looting of sites. And because many bowls are found in burials under house floors, the search for pottery results in the destruction of architecture and the desecration of burials. People who want to possess privately the beauty of a Mimbres bowl are advised to purchase some of the well-made replicas available from various sources, including Laurel and Paul Thornburg of Sonoita, AZ.

The End of the Mimbres Pottery Tradition

The style, color, and sizes of the pottery we know as Mimbres changed, more and less rapidly, during the entire period of its production, from at least 750 to 1150 AD. It became less common by AD 1150, and it was certainly no longer made by the end of the twelfth century. Instead, people in the Mimbres region began using and making an array of different kinds of pottery. An understanding of the end of this famous style provides insights into how archaeologists understand prehistoric peoples. Again, "Mimbres," is a Spanish word, a label we have applied to a river and a style of pottery, among other things. But the decline of the pottery does *not* mean the decline of a people. It simply is yet another example of a style change.

We know, through detailed studies of architecture and radiocarbon dates (Nelson & Hegmon, 2001), that people continued to live in the Mimbres region during the time that Mimbres pottery became less common. So why did the style change? Mimbres pottery is unique in the Southwest, and it is reasonable to think that it meant something special to the people who made it. Mimbres villages were among the largest and most densely populated in the Southwest at the time (with the exception of the Hohokam area in southern Arizona). Life in these villages may have been fairly difficult; the Mimbres Classic period was a time of environmental degradation, and eventually drought and subsistence stress (Minnis, 1985). The beauty of the pottery is not an indication of the ease of the artists' lives. Rather, Mimbres pottery, especially the elaborate Classic period paintings, may have been part of the tradition of living in large villages, including

the hard times. Beginning by 1130 AD, many people left the villages and resettled in small hamlets, a process known as regional reorganization (Hegmon, Nelson, & Ruth, 1998; Nelson, 1999). As people resettled, they developed new social networks and learned about new styles, which they eventually adopted as part of their changing social identities. The new generation chose to make new styles of pottery for new reasons.

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Ceramics: Rethinking Olmec Pottery

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After 1200 BCE (years presented in this entry are uncalibrated), distinctive ceramic vessels – Olmec pottery – appeared at select sites across the vast region that anthropologists refer to as Mesoamerica (southern Mexico, Belize, Guatemala, and eastern Honduras; Fig. 1). While exchange and interaction between regions existed prior to this time, in the case of Olmec pottery, the ceramic vessels display a consistent iconography that often contrasts with local pottery traditions. The iconography exhibited on Olmec pottery may represent developing religious beliefs, cosmology, and ideology, elements of which can be found in subsequent Mesoamerican groups. While features of religion and cosmology existed prior to 1200 BCE, Olmec pottery synthesizes and abstracts these concepts on durable materials. As such, understanding the origin and spread of Olmec pottery has important implications on the nature of Mesoamerican civilization.

In discussing Olmec pottery, the focus here is only on the earliest Olmec ceramic phase, which corresponds with the ascendance of the site of San Lorenzo from 1200 to 900 BCE – often referred to throughout Mesoamerica as the San Lorenzo Horizon or Early Horizon (see Pool, 2007).

Mesoamerica Prior to 1200 BCE

For millennia after the adoption of agriculture, small villages – marked by very limited political organization and social differentiation – flourished throughout Mesoamerica. In the centuries before 1200 BCE, sociopolitical change began to occur. In the Soconusco region of coastal Chiapas, early chiefdoms of the so-called Mokaya people have been documented (Clark, 1991; Clark & Pye, 2000), where competing leaders vied for prestige and redistributed imported goods, such as obsidian (a volcanic glass). Each Mokaya chiefdom was centered on a main village, such as Paso de la Amada, where leaders lived in what were probably combinations of public structures and elite residences. The importance of and reliance on agriculture in these early villages remains an important debate, with great regional variation. In the Soconusco, for example, maize was a relatively unimportant part of the diet, used primarily as a prestige food (Clark & Pye, 2000).

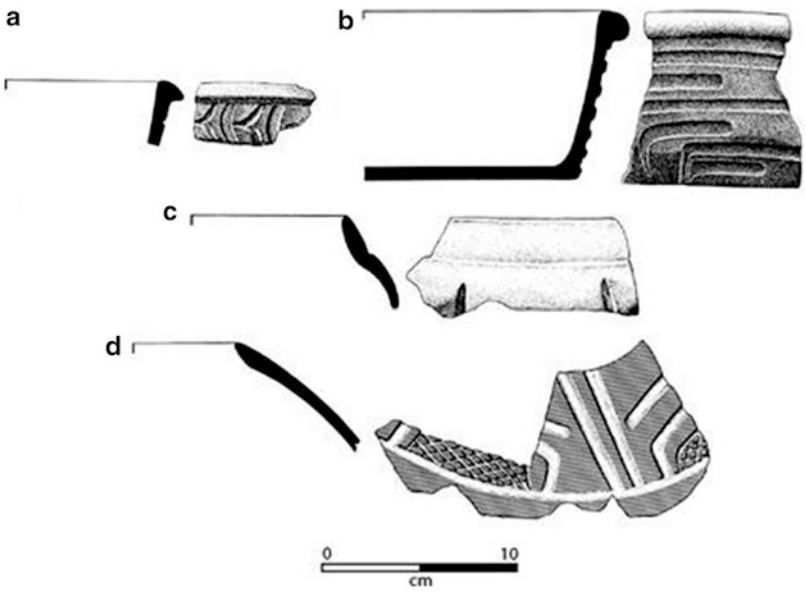
By 1200 BCE, chiefdoms also appear in the Valley of Oaxaca and the Nochixtlán Valley in modern Oaxaca state. In the Valley of Oaxaca, where most small villages covered only 2–5 ha, the village of San José Mogote had a 20 ha "downtown" area of public structures and higher-status houses which contrasted slightly with normal houses in terms of quality of construction and plaster and the occasional outbuilding or ramada (Flannery & Marcus, 1994). Similar developments occurred to the northwest, where the site of Etlatongo became the head of

Ceramics: Rethinking Olmec Pottery, Fig. 1 Map of Mesoamerica, with modern national boundaries and Mexico City shown for reference. Important San Lorenzo Horizon sites from which Olmec pottery has been analyzed are indicated

a small chiefdom in the Nochixtlán Valley. Beyond Oaxaca, chiefdoms are evident at the Basin of Mexico sites such as Tlapacoya and Tlatilco.

The Olmec and the San Lorenzo Horizon

Around 1200 BCE, all of the villages mentioned above exhibit a distinctive new style of ceramic vessels – Olmec pottery – that contrasts with local pottery traditions, which continued to be produced alongside Olmec pottery. While the origin of this pottery has been highly debated, the name applied to it – Olmec pottery, as well as the associated concept of Olmec style – has been criticized for linking this material with the archaeological Olmec people, who flourished at the Gulf Coast site of San Lorenzo, Veracruz, from 1200 BCE to 900 BCE (Blomster, 1998; Coe, 1968; Diehl, 2004; Grove, 1989; Pool, 2007). In this entry, the terms Olmec style and Olmec pottery are used separate from the Gulf Coast Olmec, to indicate that the link between Olmec-style material culture scattered across Mesoamerica and the Olmec people of the Gulf Coast is one that must be robustly documented rather than assumed. Much of the problem with the incautious use of the terms "Olmec style" and "Olmec pottery" is that these concepts were created in the first half of the twentieth century by museum curators examining looted objects, lacking provenience, prior to the discovery and exploration of the archaeological Olmec (Blomster, 1998, 2004; Grove, 1996). Thus, many objects that have loosely been labeled "Olmec style" over the past 50 years have no actual correspondence with the Gulf Coast Olmec material culture. To really discuss the Olmec style and Olmec pottery from a Gulf Coast perspective, objects from excavated and well-documented Olmec sites must be employed to define it and then compared with the many disparate objects from throughout Mesoamerica that have been labeled as part of this style (Blomster, 2002; Coe, 1965).



Ceramics: Rethinking Olmec Pottery, Fig. 2 Types of Olmec pottery at San Lorenzo, with exterior shown to the right of the profile. (**a**, **b**) Calzadas Carved pottery. (**c**) Xochiltepec White pottery. (**d**) Conejo Orange-on-White (Adapted from Blomster, Neff, and Glascock (2005, Fig. 2))

The location of San Lorenzo, on an artificially modified salt dome above the surrounding floodplain, seems to have been an important reason for the growth of this center, which Cyphers (1996, 1997, 2012; Symonds, Cyphers, & Lunagómez, 2002) estimates as close to 700 ha – dwarfing all contemporaneous settlements in Mesoamerica. San Lorenzo is almost an island among various streams and rivers, with soils constantly replenished by the Coatzacoalcos River. The San Lorenzo Olmec appear to have exerted a tight control over their immediate hinterland, with secondary sites deployed throughout the landscape for controlling the flow of resources (Symonds, 2000). Some archaeologists believe the Olmec at San Lorenzo represent a more complex form of political organization, perhaps an incipient state, while all other contemporaneous Mesoamerican regions featured chiefdoms. The debate over the sociopolitical organization of the Olmec has implications for their impact on other regions of Mesoamerica (see "Extra: The Debate on Olmec Interaction").

Olmec artists created the first monumental art in Mesoamerica, including multiton basalt colossal heads – representing Olmec rulers – and large, rectangular thrones for leaders. The Olmec style is different from other Mesoamerican art styles in formal qualities of shape, line, and space. This art is sculptural – made both in the round and in relief. In addition to the naturalistic imagery on monumental Olmec art, there is an iconographic or symbolic imagery that abstracts the important concepts of Olmec religion, cosmology, and ideology (Coe, 1965; Cyphers, 2012; De la Fuente, 1992). The sculptural nature of this style is expressed in pottery, where one of the important types (see below) features carved designs and symbols, some of which appear on monumental Olmec art.

Types of Olmec Pottery at San Lorenzo

In terms of Olmec pottery from San Lorenzo, four types have corresponding examples elsewhere in Mesoamerica (Fig. 2): Xochiltepec White, Conejo Orange-on-White, Calzadas Carved, and Limón Incised (Coe & Diehl, 1980).

Xochiltepec White pottery is made of clay so low in iron that if fires pure white. In terms of vessel shape, this type is frequently expressed in effigy vessels that represent squashes, usually without additional decoration. Conejo Orange-on-White represents a related – and even scarcer – type (Coe & Diehl, 1980, p. 179).

It exhibits the same paste as Xochiltepec White but has an orange slip, through which potters sometimes carved designs – contrasting the orange with the underlying white of the paste.

Calzadas Carved pottery exhibits distinctive carved Olmec-style symbols. Many of these stylized images contain elements of possible supernaturals referred to as the fire-serpent and were-jaguar, represented by what has been interpreted as flame eyebrows, crossed bands, opposed lines, and music brackets. Limón Incised pottery (which also includes some carved motifs) represents more abstract designs, which generally occur on the exterior of the vessel. Incised lines form curvilinear designs, emphasizing the *ilhuitl* or opposed volutes motif. Limón Incised pottery is less evident in ceramic assemblages outside of the Gulf Coast compared with Calzadas Carved.

Ceramics: Rethinking Olmec Pottery, Fig. 3 Examples of gray Calzadas Carved pottery from Oaxaca. *Left* from San José Mogote, *right* from Etlatongo (Photo by J. Blomster)

Olmec Pottery in Oaxaca

As my work has focused on Oaxaca state, I discuss primarily the Olmec pottery present in San Lorenzo Horizon villages in the Valleys of Oaxaca (home of the Zapotec people) and Nochixtlán (home of the Mixtec people). Sherds – broken pottery vessel fragments – of Calzadas Carved and Xochiltepec White have been excavated in the large village of San José Mogote (Flannery, 1968), as well as secondary sites such as Tierras Largas (Winter, 1972), in the Valley of Oaxaca. Vessels that feature Olmec designs in Oaxaca, such as Leandro Gray and Delfina Gray (Fig. 3), have been interpreted as locally made without any priority by the Olmec in their creation (Flannery & Marcus, 1994) – an example of a "peer polity" model (see "Extra"). Accumulating evidence from both the Gulf Coast and Oaxaca, however, suggests a more complicated scenario.

Excavations at Etlatongo, in the Nochixtlán Valley (Blomster, 2004), recovered a large sample of Olmec pottery in an area once characterized as peripheral to the Valley of Oaxaca in terms of both sociopolitical complexity and interaction (Marcus, 1989). In addition to examples of

Ceramics: Rethinking Olmec Pottery, Fig. 4 Cylindrical Calzadas Carved bowl excavated at Etlatongo but through compositional analysis determined to be an import from San Lorenzo (Photo by J. Blomster)

Calzadas Carved (Fig. 4) and Xochiltepec White vessels, types of Olmec pottery that have largely not been reported from the Valley of Oaxaca – Limón Incised and Conejo Orange-on-White (Fig. 5) – have also been recovered at Etlatongo. Thus, it appears that Etlatongo has a fuller suite of Olmec pottery types than the large chiefdom centered at San José Mogote.

Ceramics: Rethinking Olmec Pottery, Fig. 5 Conejo Orange-on-White vessel excavated at Etlatongo but through compositional analysis determined to be an import from San Lorenzo (Photo by J. Blomster)

Compositional Approaches to Olmec Pottery

The origin of Olmec pottery proved elusive through primarily stylistic analyses. If the peer polity model or "sister culture" model is correct, Olmec pottery made in Oaxaca should occur readily at San Lorenzo, while sites like San José Mogote should have little imported Olmec pottery. Oaxacan graywares – Leandro and Delfina Grays – have been interpreted as produced in the Valley of Oaxaca and exported to Tlapacoya and San Lorenzo (Flannery & Marcus, 1994).

In order to determine more robustly the origin of Olmec pottery, chemical characterization techniques were used. Approximately 1,000 archaeological pottery and modern clay samples from the Gulf Coast, Oaxaca state, Chiapas, and Central Mexico were subjected to Instrumental Neutron Activation Analysis (INAA) at the University of Missouri Research Reactor. This was a collaborative process, with specialists from both archaeology and compositional analysis contributing to the database and its analysis (Blomster, Hector, & Glascock, 2005; Neff & Glascock, 2002). The INAA process determines the basic chemical composition of a sample through the measurement of various forms of radiation emitted as the radioactive isotopes in an irradiated sample decay. After counts of concentrations of 32 elements have been performed, the chemical data are then analyzed in order to recognize compositionally homogeneous groups within the sample; these groups represent geographically similar zones. Samples that fall within these groups originate from the same geologic zone and are more similar to each other than samples from other zones.

Through INAA, it was possible to determine the compositional group and region of origin for 726 archaeological samples of Olmec pottery (Table 1). The results fundamentally change the way in which the production and distribution of Olmec pottery is modeled (Blomster et al., 2005).

The San Lorenzo Olmec produced both fine white paste pottery (Xochiltepec White and Conejo Orange-on-White) and decorated Olmec-style pottery (Calzadas Carved and Limón Incised) and exported them to other regional centers across Mesoamerica. Clays collected from various sites around San Lorenzo demonstrate the close chemical relationship between ancient Olmec pottery and modern clays in this region. Some Olmec pottery from other parts of Mesoamerica is in the same compositional group as those manufactured at San Lorenzo. Most regional centers produced local variants of Olmec pottery (Fig. 6), with much variation between regions.

Table 1 documents that the local variants of Olmec pottery were not exchanged between these villages. Of special interest is the data from San Lorenzo itself. A total of 203 archaeological pottery sherds were tested from San Lorenzo, and none of them come from Oaxaca or any other part of Mesoamerica. Calzadas Carved sherds found at San Lorenzo that appeared most similar to "Oaxacan variants" (Flannery & Marcus, 1994) were included in the sample to determine if Oaxacan villagers exported Delfina and Leandro Gray pottery to the Gulf Coast. Contradicting a central tenet of the peer polity model, none of the locally produced Olmec-style pottery in the sample was exported to the Gulf Coast. Instead, pots without Olmec designs, or truly localized renderings of them, may have circulated. One sherd from Etlatongo, in a style more similar to San José Mogote than anything else at Etlatongo (or San

Ceramics: Rethinking Olmec Pottery, Table 1 Regional assignments for San Lorenzo Horizon pottery (Adapted from Blomster et al. (2005, Table 2))

	Region as identified by INAA							
Archaeological context	Gulf Coast	Mazatán	Valley of Oaxaca	Nochixtlán Valley	Valley of Mexico	Chiapas Central Depression	Isthmus of Tehuantepec	Total
San Lorenzo (Gulf Coast)	203	0	0	0	0	0	0	203
Mazatán (various sites)	23	177	0	0	0	0	0	200
Valley of Oaxaca (various sites)	13	0	42	0	0	0	0	55
Etlatongo (Nochixtlán Valley)	35	0	0	26	0	0	0	61
Tlapacoya (Valley of Mexico)	17	0	0	0	87	0	0	104
San Isidro (Chiapas Central Depression)	1	0	0	0	0	41	0	42
Laguna Zope (Isthmus of Tehuantepec)	3	0	0	0	0	0	58	61
								726

Ceramics: Rethinking Olmec Pottery, Fig. 6 Small Calzadas Carved vessel determined through compositional analysis to have been made at Etlatongo, where it was excavated (Photo by J. Blomster)

Lorenzo), has a composition suggestive, but not definitive, of a Valley of Oaxaca origin.

While it is possible that if every sample of Olmec pottery at San Lorenzo could be tested, a few may come from outside of the Gulf Coast, this does not impact the general findings of this study. The Olmec at San Lorenzo generally did not receive foreign-made variants of Olmec pottery; the Olmec were its primary exporters.

Olmec pottery and associated symbols were valued by elites at the largest chiefly centers in Mesoamerica. While regions outside of the Gulf Coast made their own unique innovations and contributions to local versions of Olmec pottery, it does not appear that these other regions contributed substantially to the assemblage of Olmec-style symbols employed beyond each region. The Olmec appear to have been the primary disseminators of this pottery, which often displays rich iconography. Furthermore, important villages in adjacent regions such as San José Mogote and Etlatongo received pottery from the more distant San Lorenzo rather than from each other. It is also possible that potters, or their practices, moved and linked producers in disparate regions of Mesoamerica.

The Olmec interacted with groups across Mesoamerica that were already chiefdoms; both the Olmec and regional groups had various

interests in this interaction. The symbols exhibited on Olmec pottery suggest the dissemination of elements of Olmec religion and cosmology, which may have been received and utilized in widely different manners based on the interests of regional leaders and negotiations between and within local populations. Indeed, a fascinating aspect of this interaction is local emulation and appropriation of these symbols.

There was no one way in which these pots and symbols were disseminated across Mesoamerica. While some regions had limited, if any, entanglement with these materials and/or practices, at least one site, Canton Corralito in the Soconusco region (close to Paso de la Amada in Fig. 1), evinces the full suite of motifs, as well as vessel forms and angles virtually identical to those at San Lorenzo. Ceramic samples subjected to INAA document clear imports from San Lorenzo. Canton Corralito has been proposed as an Olmec colony or enclave (Cheetham, 2010). While investigators in the Soconusco region propose that this interaction transformed the local population from Mokaya to Olmec (Clark & Pye, 2000), the impact in the Nochixtlán and Oaxaca Valleys appears to be substantially different and less profound. At Etlatongo, both imported and locally made Olmec pottery rarely exceeded 5–10 % of the total ceramic assemblage from discrete contexts (Blomster, 2004). Access to foreign produced versus local imitation may reflect increasing differences in social status within the Etlatongo society. In Central Mexico, the impact also appears limited.

Extra: The Debate on Olmec Interaction

Much of the debate over Olmec interaction revolves around two perspectives. The nuclear-linear or so-called "mother culture" school views the Olmec as a precocious group in terms of social complexity, synthesizing and disseminating traits essential to all Mesoamerican societies. While Covarrubias (1957) proposed the Olmec created Mesoamerican civilization, modern proponents reject this idea, arguing that while the Olmec had achieved a different level of sociopolitical complexity than their contemporaries, they interacted with groups that already exhibited complexity (Diehl, 2004). Due to the charged nature and contested meanings of the term "mother culture," scholars who explore Olmec influence in Mesoamerica attempt to move beyond this term by focusing on the actual impact of the Olmec outside of the Gulf Coast (Neff et al., 2006b).

The peer polity model or so-called "sister culture" school views the Gulf Coast Olmec as just one of many groups utilizing a shared symbol set with other regions of Mesoamerica, without any priority in developing these symbols or attainment of a fundamentally greater level of social complexity (Flannery, 1968; Flannery & Marcus, 1994). Proponents of this perspective view the Olmec as a chiefdom, although the ongoing research at San Lorenzo (Symonds et al., 2002) demonstrates the more complex sociopolitical organization of the Olmec relative to contemporaneous groups.

Peer polity supporters (Flannery et al., 2005; Stoltman et al., 2005) contest the results of the INAA of Olmec pottery project, claiming a different approach to analyzing the ancient pottery – thin-section analysis (which looks at specific minerals in sherds) – contradicts the results of the INAA, viewing one method as superior to the other. The reality is these two methods complement each other. The conclusions of the Flannery and Stoltman group lack a substantive sample of local geology around San Lorenzo. Their claim, for example, that the volcanic materials in pottery excavated at San Lorenzo prove they are made in Oaxaca (Stoltman et al., 2005) founders on the fact that volcanic materials are also present in soils around San Lorenzo, as documented by a petrographic analysis from the Cyphers project at San Lorenzo (Neff et al., 2006b). The INAA project (Blomster et al., 2005; Neff et al., 2006a) documents that the Gulf Coast Olmec produced and disseminated Olmec pottery. While this research contributes to a stimulating debate on Olmec interaction and contrasting scientific methods, basic questions about what the Olmec and the various groups received from this exchange await further exploration.

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Chao Yuanfang

Fabrizio Pregadio

Virtually the only known detail of the life of Chao Yuanfang, Chinese physician and medical author, is that he was Medical Erudite (*taiyi boshi*) at the court of the Sui dynasty sometime between 605 and 616. In that position he supervised the compilation of the *Zhubing yuanhou lun* (Treatise on the Origin and Symptoms of Diseases), the first Chinese text comprehensively devoted to etiology and symptomatology. The work, which is integrally preserved, was submitted to the throne in 610.

The 50 chapters of the *Zhubing yuanhou lun* discuss more than 1,700 syndromes, classified into 67 categories of internal and external diseases. The final sections are concerned with gynecology, obstetrics, and pediatrics. A special feature of the text lies in its therapeutic methods. Rather than ingestion of drugs or acupuncture, Chao advocated a therapy based on such practices as diet and *daoyin* (a set of bodily postures, similar in some respects to Indian *hatha yoga*). The ► Huangdi neijing (Inner Canon of the Yellow Emperor) provides the broad theoretical foundation to Chao's work.

The *Zhubing yuanhou lun* exerted a remarkable influence on the history of Chinese medicine, as reflected for example in the ► Qianjin yaofang, written by ► Sun Simo. It was highly esteemed in Japan as well, where it inspired the classification of diseases in the earliest extant medical compilation, the *Ishinpō*.

See Also

► Acupuncture
► *Huangdi Neijing*
► Sun Simo

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Chemistry in China

Anthony R. Butler and Christopher Glidewell

Of all the sciences in antiquity chemistry was one of the least understood. Until people had some comprehension of chemical elements, compounds, atoms, molecules, ions, and bonding, they found it difficult to make much sense of the chemical processes occurring naturally. This does not mean that there is no real history of chemistry; it means only that we should assess the early chemical practitioners on the accuracy of their observations rather than that of their interpretations. The modern Chinese term for chemistry is *huaxue*, the study of change, and what the ancient Chinese did well was to note and describe the chemical changes which were observed when substances were mixed, heated, dissolved, or treated in some way. The fact that their interpretation may seem a little abstruse by modern standards does not detract from the worth of their observations.

Before chronicling chemistry in ancient China it is important to understand exactly what had stimulated an interest in chemical processes. The Daoist religion sought to lead its adepts into such a harmonious relationship with the world that they would escape the horrors of disease and the tragedy of death. It was not life after

death but life without death, although the precise notion varied from age to age. Those who had discovered the *dao*, through meditation, study, forms of exercise, appropriate sexual activity, and purity of life, would retire to an isolated mountain retreat and there live in complete harmony with nature. They were called *xian* or "immortals," nearer to gods then men. The idea of longevity as a reward for the godly life is not unique to Daoism; similar notions occur in Judaism. In the genealogy of the patriarchs we read, "And Enoch walked with God after he begat Methuselah three hundred years and begat sons and daughters" (Gen. 5^{22}). However, what is special to Daoism is the use of drugs to acquire immortality.

Until the Song dynasty, Chinese drugs were grouped into three classes: superior drugs which allowed one to realize vital powers, medium drugs to enrich one's nature, and inferior drugs which cure disease. This particular classification is given in *Zhenghe bencao* (Herbal of the Zhenghe Era) and it is the superior drugs that became associated with the attainment of immortality. Initially the drugs were quite crude materials: minerals straight from the ground or dried herbs, but subsequent developments lead to the compounding of these "simples" to give "elixirs of immortality." It was in the preparation of elixirs that the ancient Chinese made their first chemical observations.

The preparation of elixirs was not an activity associated with a popular or debased version of Daoism and abhorred by the more sophisticated Daoist adepts. Although the importance of elixirs in Daoist practice varied somewhat from dynasty to dynasty it always played some part in the pursuit of the Daoist goal. Several emperors of ancient China expended considerable effort to obtain the elixir of life. Shihuangdi (259–210 B.C.E.), of the Qin dynasty, equipped large expeditions under the command of Xu Fu and others to go abroad to uncover arcane secrets of preparing elixirs. Emperor Wu (156–87 B.C.E.) appointed numerous magic specialists to high positions.

Two prominent components of Daoist elixirs were cinnabar (mercuric sulfide) and gold. The reasons for this selection are not difficult to appreciate. Cinnabar is bright red, reminiscent of healthy blood, and it was thought that the infusion into the body of extra healthy blood would enhance health and lifespan. The absence of understanding of chemical composition among the ancient Chinese meant that the physical appearance (i.e., the color) had greater significance than the obviously different chemical properties of cinnabar and blood. Gold was probably the most prized component of an elixir because it was obtained from the ground in an uncombined (and thus, uncorrupted) form and in the air it did not tarnish. If these attributes could be acquired by the human body then it would, indeed, last forever. One difficulty recognized by Chinese alchemists was that both cinnabar and gold are insoluble in water and, therefore, unlikely to be absorbed in the body. Much effort, therefore, was expended in devising methods of solubilizing both cinnabar and gold.

A manual in the Daoist Patrology (*Dao Cang*) entitled *Sanshi liu Shui Fa* describes the use of niter (potassium nitrate) in vinegar (dilute ethanoic acid) to bring numerous minerals, including cinnabar, into solution. In some cases there appears to be some confusion between solution and suspension; in other cases solution would occur in any aqueous solvent. However, in a few cases, particularly in the solubilization of cinnabar, some interesting chemistry is involved. A solution of pure niter in pure aqueous ethanoic acid has no effect on cinnabar but solubilization does occur if chloride ion is present as an impurity. This is probable as niter was obtained from marine sources. Thus the fanciful descriptions of Chinese alchemy may have a sound basis in chemistry if allowance is made for probable impurities. The same applies to an account in the *Sanshi liu Shui Fa* for the solubilization of gold where the required contaminant is iodate, a common impurity in crude niter deposits. The fact that these accounts of Chinese alchemical activity can be explained in modern chemical terms is evidence of the accuracy of the original observations.

Gold is not common in China and it was not regularly used as a form of currency. Because of

the shortage of gold, much alchemical activity was directed at making gold from more commonly available materials. This appears, at first sight, to be identical with European alchemical activity but the motivation was completely different. In Europe it was, until fairly late in the thirteenth century, the pursuit of wealth; in China it was from earliest times the pursuit of immortality. Cinnabar was a popular material upon which to work (gold and cinnabar often occur together in the earth) and the *Gui Jia* Wen contains the lines:

> The span of life is up to me, not heaven.
> The reverted cinnabar becomes gold, and millions of years are mine.

In the most famous alchemical manual (the *Neipian* of the *Bao puzi*) the author, ► Ge Hong, gives a recipe for preparing gold from tin by heating with various forms of alum (potassium aluminum sulfate) on a horse dung fire. What was made was tin sulfide or mosaic gold, a yellow material which glitters just like gold. Present-day repetition of the procedure, using an electric furnace rather than a horse dung fire, confirms the production of tin sulfide.

The elixirs made from simples like cinnabar and gold contain, in general, so many components, some of which will contain impurities, that it is difficult to hazard a guess at what chemical changes are occurring. Picturesque titles were given to many elixirs. A mixture of calomel (mercuric chloride), cinnabar, sulfur, and realgar (arsenic sulfide) was known, according to the *Danjing Yaojue* of ► Sun Simo of the Tang dynasty, as Grand Unity Three Envoys Elixir. Needless to say, the elixirs did not have the required effect and their use in Daoist practice gradually died out, leaving only a memory of sustained but flawed chemical activity. There are just a few exceptions to this generalization of futility in Chinese alchemical activity, the most famous of which is the production of ► gunpowder, known originally as *huoyao* or "fire drug". Niter and sulfur are mentioned in early *materia medicas*, including *Shennong Bencao Jing* from the Han. Possibly in pursuit of elixirs, they were mixed and inadvertently contaminated with carbonaceous materials, giving a material which burned very brightly. Careful adjustment of the proportions gave an explosive, used in China for firearms and civil engineering and for fireworks. The first printed recipe for gunpowder is given in a military manual, *Wujing zongyao* by Zeng Gongliang, printed in A.D. 1044. It was the optimized formula which traveled to Europe and had such a dramatic impact on the conduct of warfare. It is ironic that the most significant achievement of Chinese alchemists in their efforts to make elixirs of immortality was an instrument of warfare.

With a decline in interest in alchemy during the Yuan, Meng, and Qing dynasties, there was no emergence of modern chemistry from alchemical activity as there was in Europe. The advanced state of modern Chinese chemistry (epitomized by the laboratory synthesis of insulin in 1965) is due to the introduction of chemistry from the West during the nineteenth century, partly by missionaries and partly by young Chinese students studying in Europe and America. Among missionaries (although the term is not entirely appropriate) was John Fryer, the son of a poor English clergyman, who worked at the Kiangnan Arsenal translating manuals and textbooks for the Chinese government. Between 1867 and 1897 he acted as focal point for the propagation of western scientific ideas in China. Even during the political upheavals of the first part of this century, there was a general increase in Chinese scientific education, and a number of Western style scientific institutions, like the Peking Union Medical College, were established. In chemical research the dominant figure was Wu Xian. He completed his Ph.D. at Harvard Medical School in 1920 and returned to the Peking Union Medical School. By 1925 he was a full professor and initiated an extensive program of research into blood chemistry. Chemical research started elsewhere and, fueled by the innate talent of the Chinese people, it has grown, in spite of all the political upheavals of the Communist revolution and the downfall of Mao, to make China one of the leading nations in the world for chemical research.

See Also

► Alchemy in China
► Ge Hong

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Chen Yan

Hong Wuli

Chen Yan, a famous physician of the Southern Song Dynasty in the twelfth century, was born in Qingtian (now in Zhejiang Province), with Wuze as his surname and Hexi as his nickname. He was extraordinarily clever and proficient in prescription and pulse taking, as well as in treatment. It was said that he could prophesy the prognosis of incurable diseases. In 1161, he assembled a six-volume work of prescriptions, *Yi yuan zhi zhi* (Treatment Based on Etiology), with 81 categories which deals with the pulse and diagnosis of diseases, followed by their etiology, and the variorum of the *Canon of Pulsology*, all with relevant recipes. This work was never published.

Chen was especially interested in the study of pathogenesis. He claimed that the causes of all diseases could be divided into three categories; this was based on Zhang Zhongjing's hypothesis. Eventually, he compiled the *San yin ji yi bingzing zheng fang lun* (Discourses on the Manifestations and Recipes of Diseases of Three Pathogenic Categories) in 1174, in 18 volumes. He summarized all pathogens into three categories:

1. Endogenous emotional changes, the Seven Emotions (joy, anger, sadness, ratiocination, grief, apprehension, and fear), which originate from the internal viscera and affect the extremities.
2. Exogenous pathogenic factors, the Six Excesses (wind, cold, heat, damp, dry, and fire), which originate from the channels and affect the internal viscera.
3. Causes neither exogenous nor endogenous, which derive from immoderate food and drink, wounds, ulcers, and insect and beast bites. The etiological work exerted some influence on later generations.

Chen also summarized medical science in four Chinese characters, reading "title, substantial property application" claiming that all new commentaries on ancient classics could be categorized under four branches: sphygmology, manifestation, disease, and treatment. Hence, all medical students should recognize a disease on the basis of pulsology and make a diagnosis on the basis of manifestations.

In the years 1165–1173, he compiled the *Herbology of Compiled Categories* with subheadings based on the above-mentioned ideas. Though it was an anonymous compilation with a "Preface by Master Hexi," it was commonly believed to be Chen's.

See Also

► Medicine in China
► *Yinyang*
► Zhang Ji (Zhang Zhongjing)

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Childbirth

Margarita A. Kay

The pelvic changes that evolved when hominids became upright walking creatures resulted ultimately in what is known as the "obstetrical dilemma" for humans. The woman's pelvic bones must not obstruct safe passage of the infant's head, and her soft vaginal tissue must be able to stretch to the maximum. Meanwhile, the baby must be mature enough to survive outside the woman's body but small enough to pass through her narrowed birth canal. Managing childbirth within these parameters developed throughout human history by means of observation, trial, and errors accommodated, however, by high fertility. Obstetrics conducted in hospitals is a recent biomedical specialty, and in the past decades, Western obstetrics has developed still more technologies. However, for non-Western mothers, little has changed in 2,500 years of written record. From that record, we can draw one of two opposing conclusions: first that childbirth customs are appropriate adaptations to biological needs; or, second, that high technology is always better than childbirth in a natural setting.

Some writers portrayed childbirth practices in non-Western societies as ideal, resulting in a quick and painless process. Men who were not allowed to observe births were told about them by informants who themselves also had been excluded from the birth scene. These writers believed that the non-Western woman just goes in the fields, gives birth, and returns to work in a few hours. Later, women anthropologists who observed non-Western births gave very different reports. Management of childbirth anywhere requires attention to the problems of safety, pain, fatigue, protracted labor, malposition of the fetus, delivery, expulsion of the placenta, and healing. Solutions to problems are mandated by the universal physiology of childbirth. In Western obstetrics, these problems of childbirth are managed with technological equipment; in non-Western societies, the same problems are managed with hands.

Childbirth is not only a biological occurrence; it is also a sociocultural event. Differences in the management of birth reflect different values and beliefs. In some cultures, myth is used to explain pregnancy and birth. Sometimes birthing is a private process, sometimes a communal event. How a society reacts to physiological processes and the extent to which there is contact with other cultures accounts in part for diversity in the ways of managing childbirth. Each birthing system relates to the place women hold in a community, the value given individual children in that community's social structure, how much medical care is available and how it is distributed, and the religious belief system that is in place. Thus childbirth practices develop within the context of each particular society.

Such cultural strictures determine, among other things, how the pregnant woman should behave, who should take care of her, how abnormalities are to be explained and how to prevent them, what, it is believed, causes labor, how it should be stimulated, where the birth should take place with which persons in attendance, and what should be done after birthing for mother and newborn. Descriptions of diverse birthing practices can be found in the writings of George Engelmann and Hermann Ploss, Max Bartels, and Paul Bartels. Birth customs are catalogued in the Outline of World Cultures. MacCormack and Kay edited anthologies detailing birth practices in mostly non-Western cultures. Following are illustrations of some of this diversity from East India, Japan, Malaysia, the Navajo Nation, Seriland of the northwest coast of Mexico, Guatemala, Mexico, Ireland, and Ibo and Bariba tribal homelands in Africa.

Many "normal" activities of women are proscribed during pregnancy with the view of preventing childbirth difficulties. Some of these prebirth customs, are considered adaptive by

Western medicine. For example, pregnant American Indian women are urged to keep moving and working during pregnancy and to limit their intake of food. The goal is not to have too large an infant for easy delivery. In West Africa, on the contrary, women are fattened in order to make them desirable for marriage and childbearing. Each custom is beneficial: genetically, American Indian women tend to have very large infants, whereas the babies of African and African-American women are likely to be quite small.

The women themselves explain their customs only as "we have always done it that way." The outsider sees the rationale for many proscriptions deriving from principles of sympathetic magic, like affecting like. Ancient Mexicans and recent Navajo, for example, believe that weaving is dangerous during pregnancy because the umbilical cord will tie up the baby. This belief has a very long history. It is recorded as fact by ancient Greek authorities of Aristotle, Galen, and Soranus. Across Western and non-Western cultures, the woman and sometimes her mate are told to avoid certain foods and actions to prevent problems in birthing or abnormalities in the baby. Conversely, a woman's cravings for exotic foods must be satisfied or the baby will be marked. Some of the rules placed to solve birth problems may be seen in the belief system of the larger culture; for example, the *bidan kampung* (traditional midwives) of Muslim Malaysia consider the humoral system of Islam in selecting a western-facing direction (with modification for days of the week) to align the woman for birthing; west faces Mecca. For Navajo, on the other hand, it is vital that the mother's head *never* face west, for that is their direction for death. Women who are taught that congenital malformations are caused by unnatural phenomena wear amulets to protect the unborn child. Charms include medals, pictures, and prayers that represent their religion, iron filings, and pieces of crystal, coral, or jet. It could be said that magical thinking can also characterize high technological Western cultures, for childbirth outcomes cannot always be predicted. Rituals of testing are enacted to resolve anxiety of the unknown. Childbirth is feared to a certain extent by all people.

Non-Western women are given prenatal massages in many cultures, notably Japan and Mexico. The purpose of the massage is to fix the fetus in a position favorable for delivery. In some societies, the fetal position is also assisted by a belt around the woman's abdomen. The Japanese apply the maternal *obi* in a special ceremony in the fifth month of pregnancy. Mexican women wear a narrow red cord, which shows the ascent of the uterus. Traditional Navajo women maintain their custom of wearing a red belt woven with green figures, 5–6 in. in width, throughout pregnancy. This belt is later used during labor and delivery.

When a woman believes that her childbirth labor is starting, she takes herbal teas. Mexican women drink *té de manzanilla*, camomile tea, believing that if it is false labor, the tea will make the pains go away, and if it is true labor, the pains will come stronger and harder. This belief has pharmacological support. Navajo women use tea from a penstemon for the same purpose, or one from rabbitbrush. Ideally, the birth should be fast. Mexican and Guatemalan women are given the ancient Aztec herb *cihuapatli*, which has strong effects on the uterus. They are permitted little sleep but are encouraged to walk with their contractions to hasten delivery. When in pain they are allowed to scream, unlike West African Bariba and Ibo. The proud Bariba women attempt to deliver alone to conquer their fear. Traditional Navajo women were trained to make no sound in order to preserve the secrecy of the process and today are silent and motionless during labor.

Because childbirth is the obvious result of sex, women in societies that value female purity, innocence, and virginity have particular difficulties. Irish peasants hide their pregnancies as long as possible, and do not publicize births. Hindu women also do not advertise their condition, resulting in little attention to their prenatal health, and distressing labor. Following Biblical injunction, the laboring woman was expected to suffer, until in the mid-nineteenth century, Queen Victoria accepted the newly discovered anesthesia for her birthings.

In non-Western childbirth, a midwife conducts the birth process. She uses many ways to stimulate labor, from placing an amulet on the laboring woman or an axe under her bed, to giving herbal teas or some of the husband's semen for her to swallow. To lubricate the birth canal, she massages with whatever is typically available, such as lard, clarified butter (*ghee*) or cooking oil.

Posture during labor also varies. In many non-Western societies, the laboring woman is encouraged to keep an upright position, utilizing gravity to move the fetus in the birth canal. Anderson and Staugård summarized traditional birth positions of 22 tribes in Africa and found kneeling to be used in 12, squatting in 10, holding rope in 7, lying in 6, and half sitting in 5. These postures may relate to different pelvic dimensions; for example, women of Biafra commonly used the squatting position, which works best for women who have a short pelvic outlet. The 80,000 women who have had traditional genital surgery (female circumcision) present special challenges for safe delivery, because scar tissue does not stretch.

A common practice of American Indians has the woman in either a kneeling or squatting position, with one attendant supporting the woman from behind, pushing on the abdomen above the uterus, while another attendant is in front, pressing from below. The mother might be pulling on a rope during contractions. Or she might pull on a hammock, which is suspended above where she stands, as has been recorded for the Kalopalo Indians of Central Brazil. In the latter case, four attendants help the laboring woman, two pressing down on each shoulder, and two pressing on her feet to direct force during a contraction. Navajo women pull on the special red belt that they wore during pregnancy, looped over a beam in the ceiling. For the Seri, a hunting – gathering people of Sonora, Mexico, two women who are usually close relatives help with the birth. One assistant sits on the ground, her legs spread but her knees doubled under her, to make a lap for the parturient to sit on. The second assistant, also sitting on the ground but facing the laboring woman, holds her hands in position to receive the infant. The parturient and midwives often wait for hours in the described positions. To speed the labor, the parturient may be given tea from the roots of indigenous plants, or a concoction of alcohol, limes, cinnamon, and aspirin. The women often say that they do not want to marry because childbirth hurts too much. Women of the nearby agricultural Yaquis drink an infusion of the narcotic plant Datura for childbirth pain.

For difficult deliveries, Punjabi midwives straddle the chest of the laboring woman, pressing hard on the abdomen with their hands; or they push with the heels of their feet on the pubic bone.

In matrilineal societies such as the Navajo, the attendants are commonly women from the maternal side of the family. Patrilineal societies such as Egyptian or Japanese, where descent is traced through the father's line, require the presence of the husband's kin, to assure continuity of the line. The birthing woman is accompanied by her husband's mother, and goes to her mother-in-law's house to recuperate from the birth.

Delivery of the placenta (afterbirth) is a grave concern in all societies. The medical ethnobotany of every group contains a variety of plants to give the woman whose placenta is slow to separate. According to humoral doctrines which are prevalent in many non-Western cultures including India, China, Middle America, and Latin America, those herbs that acted on the uterus were categorized as "hot" and "dry," and many of the same plant genera are used crossculturally. A retained placenta is a most dreaded complication of birth: "anyone can deliver a baby but it is the placenta which kills" (Bariba). Once the midwife delivers the placenta, she disposes of it according to its meaning in her culture, respect as a spiritual entity or fear of its power. In Malaysia, the placenta is considered to be the fetus's semi-human sibling, and thus is washed and ceremonially buried, which is similarly done by Guatemalans and Seri.

Some of the materials used to act on the uterus, either to bring on menstruation, stimulate labor, hasten birth, or separate the placenta, have been subjected to phytochemical analysis. *Artemisia* species, the botanical name first given by the

Greeks for their goddess of women, and used worldwide in Europe, the Middle East, China, Latin America, North America, and Mexico, contain estrogens, female hormones. *Matricaria*, named since Roman times from the Latin word for womb, relieves painful uterine cramps through its spasmolytic compounds. Analysis of other materials, such as the husband's semen, given to the laboring woman in some African cultures, shows that they are high in prostaglandins, chemical compounds used in biomedicine to initiate labor by causing the mouth of the uterus to begin opening.

Indian peoples of Mexico use plants passed down in oral history from Uto-Aztecan forbearers (such as *yyahautli*, marigold, to stimulate labor, and *toloache*, jimson weed, for labor pain) and also those learned from Europeans who came in the colonial period, coriander and rosemary, for their actions on the uterus. Hindu mothers are given Ayurvedic herbs, while Chinese herbs are used all over eastern Asia. Childbearing women take herbs for prenatal care, labor strength, and postpartum healing. The woman may drink the plant material in teas; it may be applied to her abdomen, inserted in her vagina, inhaled, or she may sit over infusions in vapor baths.

After the baby is born, the umbilical cord must be tied and cut, and again there are many practices to be followed. The cord is cut with a piece of sharp ► bamboo in Malaysia, a razor blade or broken glass in Ghana. It may be tied with hair, string, or animal tendon. The variety of dressings include pounded pottery, herbs, salt, ground shells, and ash, materials that can harbor bacilli causing neonatal tetanus. The cord remains may be buried in a place that is associated with the anticipated sex role behavior of the child. For example, a Navajo woman may bury her infant son's cord near the sheep corral and her infant daughter's cord near the weaving room. Mexican, Malaysian, and Japanese mothers kept each child's cord for the child's future welfare.

The immediate postpartum period lasts for 3 days in cultures predominately Christian, and 4 days in American Indian societies, the respective magic numbers for each. After giving birth, and for a period of time prescribed by the culture, 20 days for many American Indians, 40 days for traditional Jews, Christians, and Muslims, the woman is supposed to be confined to her home. It is believed that the woman is vulnerable, requiring protection during the entire postpartum period. Some Mexican patients still observe *la dieta* during which time baths, walking barefoot, and otherwise being subjected to cold are proscribed. This includes avoiding "cold" foods, foods that are believed to have a quality of chilling the body.

The newly delivered woman is healed with heat in many cultures. The Navajo woman may have heat applied by warming green cedar and holding it to the abdomen with her red sash. She is bathed on the fourth day after delivery, especially if she had a ceremonial Sing during her labor. Her lacerations are treated with a salve of baked cactus, or a fumigant treatment may be prepared by digging a hole and heating stones therein. Soranus described a similar fumigant 2,000 years ago. "Mother roasting," as it is called, is a therapy used by many societies in Southeast Asia, including Malaysian. A fire is maintained beside the delivered woman for a prescribed number of days. This "dries out" the womb. A ritual fire is kept burning in the dwelling of the Seri woman for 4 days following the birth, in this case for the infant's sake. Hot leaves are pressed on the Ibo mother's abdomen, immediately after birth. The *temascal* or sudatory was used by ancient Aztecs after childbirth, as well as by ancient Romans and is used by present day orthodox Jewish women after menstruation as well as after childbirth.

Sexual intercourse is not permitted anywhere until the puerperium, however defined, is over. Mexicans, like so many others, believe that intercourse when there is vaginal bleeding is abhorrent. The Navajo believe that even indirect contact with vaginal blood is very dangerous to the husband and anyone else. In many cultures, contact with blood was considered polluting to the individual and to the community. The woman could now be purified, by bath and by religious ceremony. Leviticus XII, two provides the Laws of Purification and Atonement for Jews,

Christians, and Muslims. The postpartum bath is a Shinto rite of purification in Japan.

Non-Western Birth Today

It is estimated that worldwide, 80 % of births are attended by Traditional Midwives, Traditional Birth Attendants, or simply female relatives. The status of the traditional midwife has varied through time and place. For some non-Western cultures, her status has been very low, for it is women's work, and deals with blood. With many ethnic groups in India, midwifery was looked upon as a most degrading occupation.

The traditional midwife is typically a woman who is respected in her community, nonliterate, postmenopausal, has herself borne children, and learned her craft as an apprentice to another woman. She is often looked down on by the Western medical community. Traditional midwives may get Western training to meet difficult births, although they may not always find such instruction useful. When Western technology is not available, the traditional midwife's birth skills may prove to be superior. It may be hoped that the Certified Nurse Midwives of each culture may bridge the birth customs of the non-Western traditional midwife with the practices of Western biomedicine.

See Also

► Ethnobotany
► Magic and Science

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Childbirth in India

Nitin Trasi

Obstetrics in Ancient India

The oldest sources of information about Indian culture are the four *Vedas*, sacred compositions probably compiled over several centuries during the second millennium BCE. The knowledge about Vedic medicine is contained mainly in the fourth and latest Veda, the *Atharva Veda*, and a related later work, the *Kauśika Sūtra*. Later, in the post-Vedic era, the ancient Indian system of medicine acquired the name Āyurveda (lit.: knowledge of life). The golden age of Indian medicine lasted almost 2,000 years, from about 1000 BCE to about AD 1000. The most famous works written at this time were the

medical treatises known as the ▶ *Caraka Saṁhitā* and the *Śuśruta Saṁhitā*.

The art of obstetrics was well advanced in ancient India. Āyurveda had eight branches (*aśtānga āyurveda*), one of which was *Kaumārabhrtya* – gynecology, midwifery, and pediatrics. This included the classification of diseases of the female genital tract, including menstrual disturbances, and suggestions for treatment. It discussed the clinical course and various stages of labor, difficult labor (*mūḍagarbha*), the management of the puerperium (the period of confinement after labor), and miscarriage (*makkalla*). The different malpositions of the fetus were also known, and methods of treatment by version (the manual turning of the fetus to make delivery easier), embryotomy (an operation to destroy the fetus), forceps delivery, and even cesarean section were described (Keswani & Sharma, 1972). In fact, the first mention of the obstetric forceps in world literature is to be found in the Vedas. It was called the *jugna ṣankhu*, and consisted of paired, semicircular-ended tongs, such as that used for holding hot utensils. It was probably used for extracting a dead and dismembered fetus from the mother's womb (Das, 1929; Douglas & Stromme, 1988, p. 367).

Caraka, the author of the *Caraka Saṁhitā*, was a famous physician. He is believed to have been the court-physician of the Buddhist king Kaniśka (AD 78–100), and attended on the king's wife as obstetrician during her difficult delivery (Saletore, 1984, pp. 300–301). The *Caraka Saṁhitā* lacked a detailed study of surgery, but was otherwise quite comprehensive.

Śuśruta was the most celebrated surgeon of ancient India. The *Śuśruta Saṁhitā* was originally written probably in the last centuries BCE, although some date it much earlier, even as far back as 1000 BCE. It is especially important from a surgical point of view. Śuśruta mentions as many as 121 instruments of various descriptions, made largely of steel. Alcohol in the form of medicated wines was used as a narcotic during and also after operations, and hot oils, tar, or caustics were used to stop bleeding. A drug called *Sammohinī* (producer of unconsciousness) was administered before major operations, and another drug, *Sanjīvanī* (restorer of life) was employed to resuscitate the patient after operation (Keswani 1961, 1967).

When delivery was impossible by natural means, the fetus – usually dead by then – was probably extracted using forceps; if necessary after dismemberment by embryotomy. Cesarean section, though mentioned in the literature, was not likely to have been a real choice. It had an extremely poor maternal outcome (almost 100 % mortality) the world over until the twentieth century. In ancient India too, it was probably only performed on rare occasions on a dying mother (or one who had just died) in an attempt to save the baby. Embryotomy, on the other hand, seems to have been a well-known procedure, finding mention even in nonmedical literature. The great monistic philosopher Ādi Śaṅkarācārya (AD 788?–820) refers to it, citing it as an example of human suffering even before life has begun.

If, by chance, the child moves into a transverse position at the time of delivery, it is then turned out (extracted) forcibly, broken into pieces by instruments (*Prabhodasudhākara*, v. 10).

Charitable hospitals were established by many rulers, notably Rāhul, the son of the Buddha, and the famous Emperor Aśoka (ca. 273–232 BCE or 265–238 BCE).

The Populace

Although the art of obstetrics was well advanced in ancient India, most people probably had little access to it. Pregnancy and childbirth were generally managed at home, by practices based partly on experience and partly on cultural beliefs. Girls were customarily married off at a very young age, often even before they had attained puberty. Their obstetric career therefore began early, and they continued to bear as many offspring as their health would permit. The pregnant woman was subjected to many restrictions.

The solar and lunar eclipses were believed to be especially inauspicious times for her, and she was forbidden from venturing out into the open at these times.

Childbirth was largely a domestic affair, the parturient woman being attended to by experienced elder ladies from her own and from her neighbors' families. The squatting position or the seated (kneeling) posture was often favored for childbirth, and even today many tribal societies in India prefer these positions. The vaginal canal was lubricated with clarified butter (*ghī*) and ghī was also fed to the mother in the belief that it would lubricate the birth canal. A normal delivery did not usually present too many problems, but there was no recourse when complications arose, and in such cases the baby was often lost, and at times the mother too. Unsanitary conditions and lack of proper training and knowledge contributed to a high maternal and fetal mortality. Neonatal tetanus was an important cause of infant mortality. Cow dung was believed to have purifying properties, and was commonly used to "purify" the floor of the house (Saletore, 1943, p. 114). This could have been a contributory factor.

At some time, the system of the traditional birth attendant, the *dāi*, took root. These dāis were usually experienced elderly ladies who would provide their services for a modest fee. However, though experienced, the dāis had no scientific education or training. Even today, it is estimated that dāis conduct over 50 % of births in rural India. However, since 1957, the dāis undergo scientific training, and dāi training is now an essential part of the maternal and child health program of the Indian government.

The Medieval Ages and Later

With the coming of the Muslim conquerors to India, from the tenth century onward, the golden age of Āyurveda began to decline. Some of the factors leading to the decline were want of patronage from the rulers, aversion of educated Hindus to contact with blood, pus and diseased persons, and absence of a system of regular education and training for practitioners. In the absence of professional standards, it became difficult to distinguish the genuine practitioners of Āyurveda (the vaidya's) from quacks. Medicine in India during the later medieval period was dominated by Persian and Arabic influences which introduced an amalgam of Greek and Persian medicine, known as the *Unānı system* of medicine.

From the 1800s until 1947, the British ruled over most of India (British India included what are now India, Pakistan, and Bangladesh). By then, both Āyurveda and the Unānı systems were unorganized, as they had not kept up with modern discoveries and research. Skills were passed by familial succession and not by institutionalized education, and the practitioners were for the most part uneducated and unwilling to incorporate the new knowledge and discoveries that were pouring in from the West.

The state of public health in India at the time was poor, and women and infants were the most neglected segments of society in matters of medical aid. Maternal mortality (maternal death during childbirth) and infant mortality were very high. Even when modern medical treatment was available, resistance to treatment by male physicians and the strict purdāh system prevalent among certain communities often ensured that women got little access to it. There were cases where women preferred to die in childbirth rather than submit to treatment by a male doctor (Kumar, 1998).

Modern Obstetrics in India

The Portuguese first introduced modern Western medicine to India (Royal Hospital, Goa, 1510), but it was largely the British who later established and consolidated both its practice and its study in the subcontinent. Popularization of sound

surgical practice led to great improvements in the health of the population. Specialization was introduced in Indian universities both in education and research, and India was kept abreast of all the major developments taking place in the fields of science and medicine all over the world. All-women managed hospitals were opened for women patients. In Bombay (now Mumbai), several hospitals for women were opened in the late 1800s; among them, the Cama Hospital (1886) and the Allbless Obstetric Hospital (1890) were entirely managed by women staff. Medical education was promoted among girls even at a time when this was not popular in Europe. Anandibai Joshee was the first Indian woman to go abroad for medical education. She obtained an American degree in 1886. Significantly, her MD Dissertation topic was "Obstetrics among the Aryan Hindoos" (Kumar, 1998).

In the early twentieth century, several Indian obstetricians made valuable contributions in the field of obstetrics. Some of the pioneering Indian obstetricians were Dr. N. A. Purandare from Mumbai (1877–1964) and Rāo Sāhib Dr. Shivarao Trasi (1881–1954) from southern India. In 1929, Sir Kedarnath Das published his work on the history of the obstetric forceps, which is still considered a classic, and in which he described over 500 varieties of forceps and included over 2,000 references in ten different languages. Dr. V. N. Shirodkar (1899–1971) pioneered several new surgical techniques, the most famous of which was an operation for women suffering from repeated abortions. Other leading obstetricians were Dr. K. M. Masani (1903–1988), Dr. M. K. Krishna Menon (1908–1988), and Dr. B. N. Purandare (1911–1990), among many others.

In India today, women use both traditional and modern techniques, depending on their location and income. In remote rural areas, conditions are similar to what they were a hundred years ago, while women in the city have access to top hospitals and the best of equipment. Mortality statistics are still alarmingly high in certain parts of the country.

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Cities and Towns in Ancient Israel (Bronze and Iron Ages)

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Background

Many cities have been uncovered from Bronze and Iron Age Israel, the vast majority of which were located on *tells* – artificial mounds created as a result of gradual human settlement activity. Notably, not every location is suitable for the emergence of a center, even of a local nature, and each site had advantages and disadvantages in relation to factors such as security, water supply, transportation (roads), and the availability of soils for agriculture. Consequently, only several locations could, in antiquity, provide livelihood for a large population at any given region. This resulted in a repeating pattern in which the centers of many periods were continuously located one on top of the other, thus creating the famous tells which are so typical of the Middle Eastern landscape. Although in many instances extramural neighborhoods were built on the slopes of the tells (and in some rare instances cities were not built on tells), it is only in the later half of the first millennium BCE that the overall pattern changed. By then most *tells* were abandoned, and cities were built practically everywhere. The gradual process of tell abandonment resulted from many factors, including changes in security conditions, increased population, and improved technology, but this process lies outside the scope of the present discussion.

Notably, the towns (and tells) of ancient Israel were much smaller than their contemporaries in Mesopotamia and Syria. An average city of the Bronze and Iron Age covered some 3–5 ha (and sometimes even less); larger towns, in the scale of 7–12 ha, were also present. Towns of 20 ha, however, were exceptionally large, and megalopolises of 60 ha and more were extremely rare – very few such sites existed in the periods discussed here (e.g., Hazor in the Middle Bronze Age II and Late Bronze Age and Jerusalem in the Iron Age II).

Defining a city is a complex enterprise. Within the scope of the present entry, suffice it to note that the urban centers were much larger and more crowded than their rural contemporaries. Their inhabitants were of diverse backgrounds and occupations, and not all of them were engaged in agriculture. Social stratification is evident in practically all such sites, along with public buildings and royal construction activities (palaces, walls, storehouses, water systems, etc.). These urban settlements served as political and economic centers for the villages that surrounded them and, probably also, during most periods, as centers of tax collection and as places of refuge in times of need.

History of Urbanization in Ancient Israel Up to the Persian Period

Cities first appeared in ancient Israel around the transition to the third millennium BCE (Early Bronze Age) (see section "Extra 1"). These first cities usually lie at the bottom of the tells, and in most cases not much is known for certain about their planning. It is mainly in the desert area, where the sites were not resettled in later periods, that we can discuss elements of city planning. ʻArad, in southern Israel, is the best-known example of such sites (Fig. 1).

The site covers almost 10 ha and seems to have been divided into several public and residential quarters. The former included several small temples and a modest palace. A large, but simple, water system into which rainwater was collected was unearthed in the lowest part of the city. One should remember, however, that it is not certain whether ʻArad is a representative of the Early Bronze Age urban phenomenon, as, due to its location on the desert fringe, it might have differed from the typical towns of the third millennium BCE.

The Early Bronze cities were gradually destroyed and abandoned toward the end of the millennium, and by the last two centuries

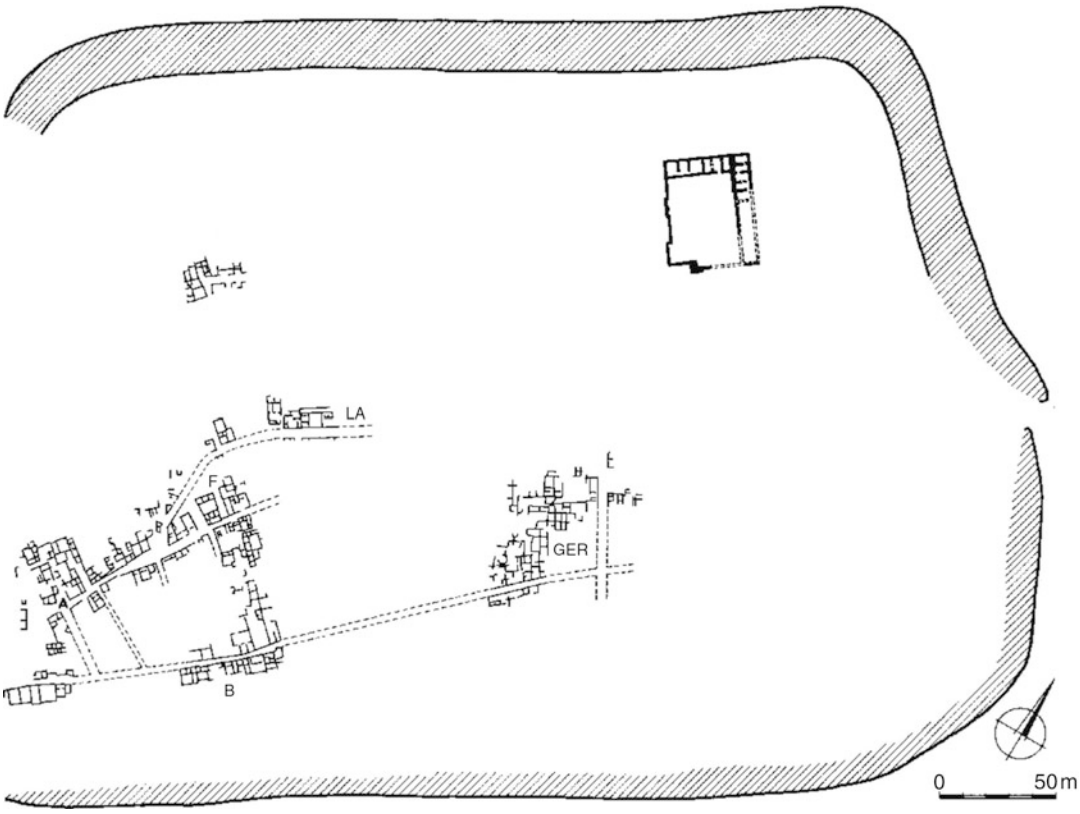
Cities and Towns in Ancient Israel (Bronze and Iron Ages), Fig. 1 The Early Bronze Age city of ʻArad (Based on Kempinski, 1992a, p. 76; courtesy of the Israel Exploration Society)

of this millennium (the Intermediate Bronze Age) Cisjordan was devoid of any urban settlement.

Urbanization resumed in the twentieth and nineteenth century BCE (Middle Bronze Age II; 2000–1550 BCE). New cities emerged throughout the country, with an emphasis on the lower regions. Port cities were built for the first time. The largest Middle Bronze Age urban center was Hazor, which was apparently part of the Syrian system of city-states. Many sites were now surrounded with massive earthworks, whose purpose, however, is in doubt, since in many instances no city wall was unearthed on top of them. Some scholars have suggested that their construction, which required much labor but very few experts, served the local leaders as a substitute for the building of large and impressive city walls, as the latter would have required more experts who were not easily available for most rulers. Some towns show signs of planning, probably following a simple grid (Tell el-ʻAjul) (Fig. 2).

While most characteristics of Middle Bronze Age culture continued during the Late Bronze Age (1550–1200 BCE), the number of towns declined, and they became smaller in size. Furthermore, hardly any settlement was fortified at the time (since the region was an Egyptian colony, the latter can probably be attributed to Egyptian policy).

Further decline occurred during the Iron Age I (1200–1000). The Egyptian domination over Canaan vanished, and many centers were destroyed or abandoned. Other towns, however, continued to exist, especially in the northern valleys, and a new wave of urbanization took place in the southern coastal plain, as a result of the arrival of the Sea Peoples (mainly the Philistines). The latter founded some new cities, for



Cities and Towns in Ancient Israel (Bronze and Iron Ages), Fig. 2 The Middle Bronze Age II center of Tell el ʻAjul (Based on Kempinski, 1992b, p. 124; courtesy of the Israel Exploration Society)

example, in Ekron, covering relatively large areas.

Urbanization in many parts of the country was gradually resumed only in tandem with the formation processes of the Israelite state, in the tenth century BCE, during the transition to the IAII (c. 970–586 BCE) (see section "Extra 2"). This urbanization probably involved, partially at least, forced settlement of population in urban centers.

The Iron Age II presents a settlement peak in the history of the region. Many urban centers were erected at the time throughout the country. Excavations have uncovered various types of cities and a complex settlement hierarchy. These range from capitals, through administrative and regional centers of different sizes, to small field towns (in addition to rural settlements of course). The largest cities of the period were Samaria and Jerusalem, the capitals of the kingdoms of Israel and Judah (respectively). At its height, the latter covered some 90–100 ha (including extramural neighborhoods) – larger than any other site in ancient Israel during the Bronze and Iron Ages. Also of significant size were several Philistine centers such as Ekron, Gath, and Ashkelon.

Excavations have revealed clear evidence for socioeconomic stratification. Most of the population lived in small houses, which probably housed small nuclear families. The wealthy and some high officials were better off and lived in large four room houses (see section "Extra 3"). In some settlements, a form of a middle class is also identified. Palaces, which were identified in several cities, represent the upper part of the socioeconomic continuum, and this is where the royal family and the highest officials lived.

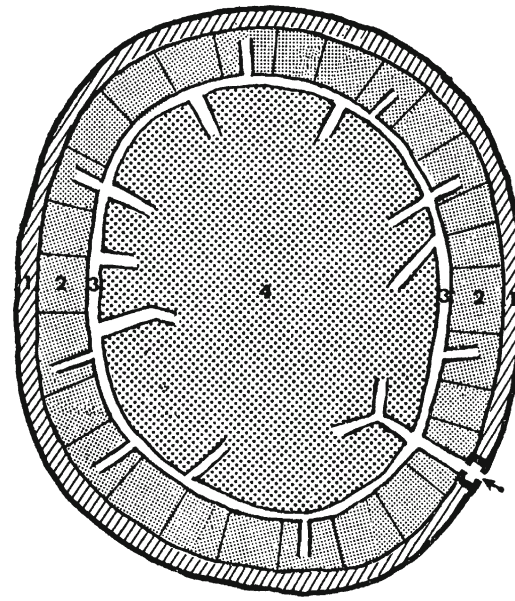
The Assyrian and (mainly) the Babylonian campaigns brought about large-scale destruction and population decline, and the number and size

of towns declined dramatically. Urbanization in the Persian Period was more limited and concentrated mainly in the coastal plain. Real large-scale urbanization reemerged only in the Hellenistic period.

Iron Age Town Planning

The Israelite towns of the Iron Age II (1000–586 BCE) have received a great deal of scholarly attention. This results from the interest of scholars in this part of the biblical period, from its being a demographic peak in which more sites existed than ever before, and because the Iron Age II usually comprises the upper strata on the tells, therefore permitting large-scale exposure, impossible for other periods.

According to Yigal Shiloh's seminal study, the basic outline of the Israelite "town plan is clear: alongside the line of fortifications there is a belt of buildings bordered on the inner side by a ring road, running parallel to the fortifications, and separating these structures from the 'core' of the city. The 'core' itself was divided into many blocks of residential units of the four-room house type and its subtypes" (Shiloh, 1978, pp. 37–38) (Fig. 3).



Schematic model of the Israelite city, based on Tell Beit Mirsim, Tell en-Nasbeh, Beth Shemesh and Beer-sheba: 1. fortifications; 2. buildings of the outer belt; 3. ring road; 4. central core.

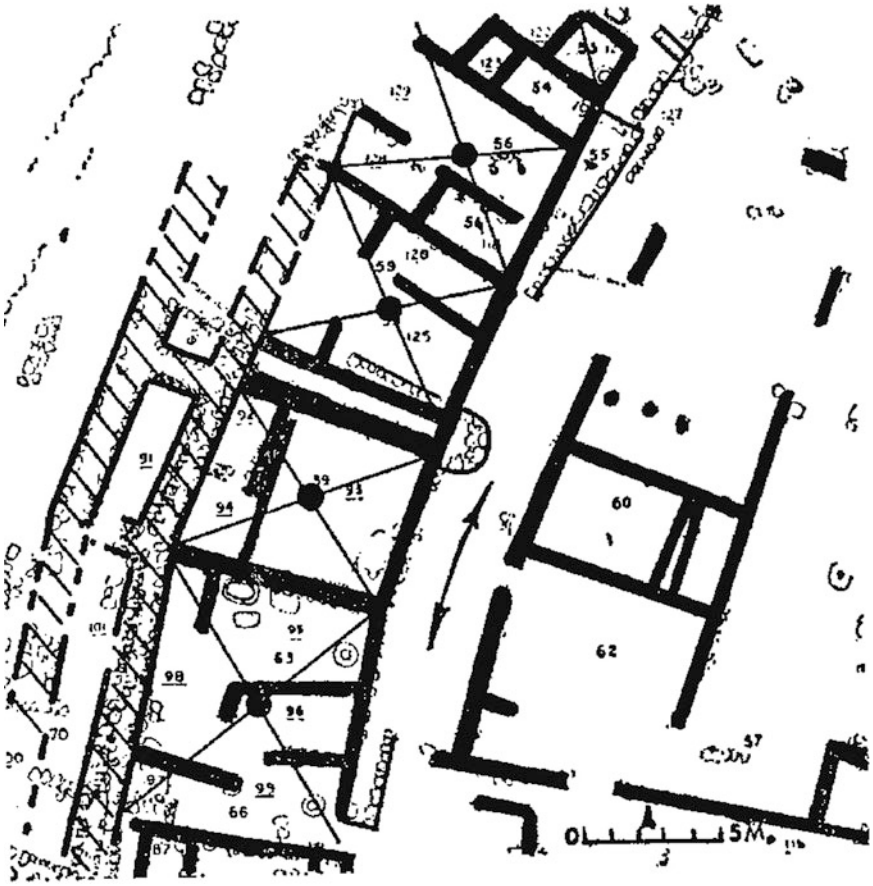
Cities and Towns in Ancient Israel (Bronze and Iron Ages), Fig. 3 A typical Israelite town (According to Shiloh, 1978, p. 41; courtesy of the Israel Exploration Society)

Apparently, the outer belt was intersected by small alleys, separating the various houses and leading to the city wall, therefore enabling free access to the wall and to its casemate rooms (when these existed) (Fig. 4).

While some components of this plan can be found throughout the kingdoms of Israel and Judah, it is more typical of the Kingdom of Judah (e.g., Beth Shemesh, Beersheba, Tell Beit Mirsim, and the recently excavated Kh. Qeiyafa). In most cities in the kingdom of Israel (and probably also Philistia), a different planning prevailed. Here the city wall was accompanied by a road, and only inside this street were buildings built, divided into quarters by smaller streets (e.g., Hazor and Megiddo).

Accessibility to the city wall seems to have been a major factor in Iron Age town planning. A besieged city which fell to the enemy suffered a horrible fate, and both types of planning enabled the defenders easy and quick access to the city walls, through the small alleys in the "Judahite" plan and from practically any place in the "Israelite" plan.

Another difference between Judah and Israel lies in the fact that most towns which were built according to the latter plan were surrounded by a solid wall, while the "Judahite" plan is usually accompanied by a casemate wall. The alleys constructed in Judahite towns enabled the authorities not only access to the top of the wall but also to some casemates, which could have been used for storage. The principle of accessibility to the city wall was adhered to in both plans, and it is likely that the reason for the adoption of different planning was due to space considerations. Larger cities could afford a massive wall and a street that ran along it. Smaller towns, in which space was scarce, tried to save as much area as possible. Casemate walls were therefore built, and the



Cities and Towns in Ancient Israel (Bronze and Iron Ages), Fig. 4 Part of Beth Shemesh city plan (Based on Shiloh, 1978, p. 40; courtesy of the Israel Exploration Society)

ring road was located inside the outer belt of houses (therefore reducing the space it consumed).

Another characteristic of the Iron Age city was a public quarter near the city gate. The impressive gate was usually accompanied by an open square, and near or around it were public structures, palaces, storehouses, barracks, water systems, etc., as can be seen in Beersheba, Tell en-Nasbeh, Beth Shemesh, Jerusalem, Kinrot, and Gezer (see section "Extra 4").

Furthermore, cosmological principles had also an influence on Israelite construction on all levels, from dwellings to cities. It seems that as part of their complex cosmology the Israelites regarded the east as the most auspicious direction and the west as the most inauspicious one (like many other societies). Accordingly, they directed their structures in an easterly orientation whenever this was possible, and when this was not the case, they, at least, attempted to avoid the west. This was manifested also in city gates, and about 75 % of those faced, roughly, the east. Following easterly orientation for dwellings in towns was difficult and was carried out in the following manner: (1) public buildings were adjacent to most of the Iron II city gates; (2) most city gates were oriented to the east.

The result was that no dwellings were built in the eastern part of the outer belt and no dwellings in this belt were expected to face the west, therefore avoiding this inauspicious orientation. The same principle was also followed inside the ring road, as in many cases houses were oriented

Cities and Towns in Ancient Israel (Bronze and Iron Ages), Fig. 5 General plan of Beer-Sheba (Singer-Avitz, 1996, p. 168; courtesy of Prof. Ze'ev Herzog, Tel Aviv University)

toward small alleys (and avoided the main street when it was to their west).

The eastern orientation seems, therefore, to have been a major principle of town planning, influencing not only the orientation of city gates but also of many dwellings and alleys.

The town of Beersheba is a good example of a planned settlement in the Iron Age (Fig. 5).

During the eighth century BCE, Beersheba (stratum II) was a small but well-planned administrative center in the Negev. Its gate was in the southeastern part of the wall, facing this direction. Inside the gate, a small square was located, surrounded by public buildings of various sorts. The city wall was accompanied with a belt of houses, which used its casemates as their backrooms, and with a nicely built inner ring road that gave access to these houses. The outer belt of houses was intersected in various points by small corridors that connected the ring road with the casemate walls, enabling easy access to the wall and to some of its casemates. The inner part of the town – its core – was divided by smaller streets which cut through it, dividing it into blocks of houses.

The eastern part of the outer belt of houses was composed of public buildings and did not include any dwellings. The dwellings in this belt, therefore, were oriented to the south, east, and north, but not to the west. Houses in the inner blocks

were oriented toward the inner streets, usually avoiding the west. Adhering to the eastern orientation caused them, in some instances, to orient their backs to the main street and to face small alleys.

Extra 1

Notably, the emergence of towns was a long process, and it is not always easy to identify the exact point in time from which a settlement should be called a city. Some settlements were quite large and complex already in the last phase of the fourth millennium BCE (Early Bronze Age I, traditionally regarded as a "proto-urban" period), and some have suggested that these were the first cities. Other scholars, however, questioned the validity of the term "urban" not only for the centers of the third millennium BCE but even for those of the later phases of the Bronze Age, suggesting that they were just complex villages. Most scholars, however, accept the traditional view and regard these large settlements as cities.

Extra 2

The transition from the Iron Age I to the Iron Age II witnessed the gradual disappearance of rural settlements in most parts of ancient Israel. It is suggested that at least part of this process resulted from a policy of "forced settlement." The newly established Israelite monarchy transferred some of the population (especially in the newly conquered territories) to other/new settlements, and mainly to cities, in order to facilitate better control of the population, to lower costs, and to minimize the efforts involved in delivering sanctions, be it normative, remunerative, or coercive while maximizing its effectiveness.

Extra 3

The term "four-room house" is a convention used to designate the typical Iron Age dwelling in ancient Israel whose ideal plan is composed of four main rooms. The typical house includes three parallel longitudinal spaces that are backed by a broad room, with the entrance located at the central longitudinal space. The "rooms" are really spaces/areas and can be subdivided. There are subtypes of the "ideal" form, comprising three or two "spaces" and, in exceptional cases, even five "spaces." The high popularity of the four-room house was explained as either expressing its close relation with the Israelites (without elaborating the reasons for this relation) or its functional suitability to the needs of the Iron Age peasants, regardless of their ethnicity. Neither of these explanations, however, seem to account for the synchronic and diachronic dominance of the four-room house as a preferable architectural type in all levels of Iron Age settlement (from cities to hamlets; private dwellings and public buildings), all over the country (both in highlands and lowlands), for almost 600 years(!). It is likely that an adequate explanation for the unique phenomenon of the four-room house must relate to the ideological/cognitive realm and to its place within the Israelite social and spiritual worlds.

Extra 4

A typical public building in Iron Age towns is the "tripartite pillared building" (see Fig. 5, to the north of the gate). Such structures were discovered in many cities (especially near the city gate), but their interpretation varies greatly: the most common interpretation is that of a stable or a storehouse. In most instances, however, large quantities of domestic pottery (mainly bowls, jugs, juglets, cooking pots, and also storage jars) were found on the floors of these buildings. Since the finds do not easily fit with the above interpretation, some scholars have raised additional possibilities, including barracks, covered markets, customs house, and a multipurpose public building which had many functions, including a shelter for the poor.

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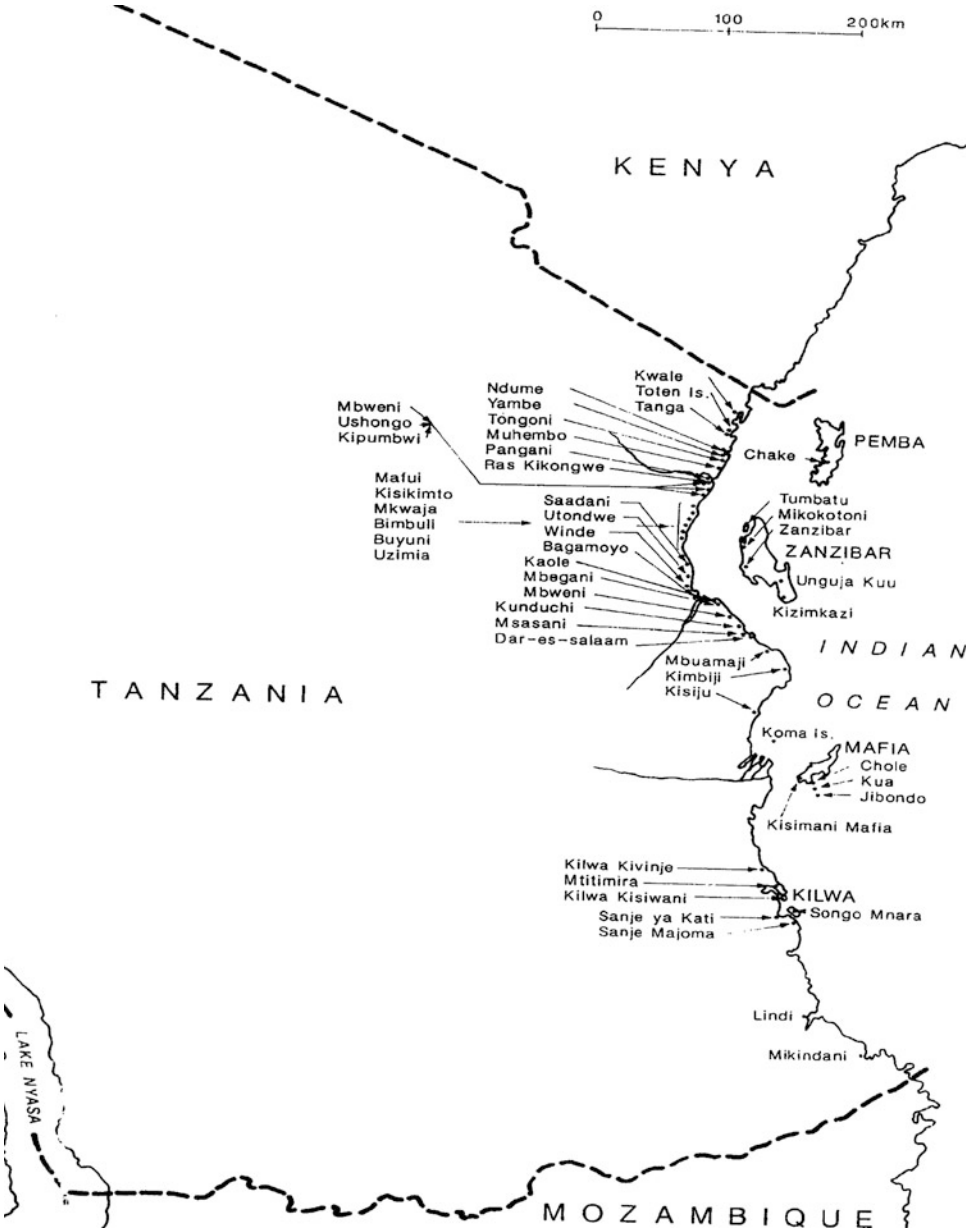
Cities and Towns in East Africa

Felix Chami

The towns of East Africa were built during two periods: pre-colonial and colonial. The former grew up along the coast, facilitating trade and communication between the rim of the Indian Ocean Seaboard and the interior of Africa. The towns, better known in history as Swahili City States, survived from about the beginning of the second millennium AD to about the 1890s. The latter were mostly new administrative centres established with the launch of German and British rule in East Africa from about the 1890s. Only a few settlements of the colonial period had a history pre-dating the colonial era. Such towns include Mombasa, which is a Swahili town, and Mengo in Kampala, which was the seat for the Buganda Kingdom. This article examines the pre-colonial Swahili towns.

The Growth of the Swahili Towns

Swahili settlements spread all along the coast and islands of East Africa (Fig. 1). There were few settlements before the Swahili towns of the thirteenth century, mostly built with mud and



Cities and Towns in East Africa, Fig. 1 The Swahili towns on the Tanzanian coast. For the rest of East African coast (see Horton & Middleton, 2000, pp. 6–7)

wattle. Concentration of these towns seems to have first occurred in the Mafia-Kilwa region on the coast of Southern Tanzania and on the Lamu Archipelago on the northern coast of Kenya. Individual settlements seem also to have flourished elsewhere on the coastal littoral and virtually on every island large enough to settle from Lamu archipelago to Madagascar. These early settlements are identified by archaeologists by remains there of early Islamic goods including Sassanian Islamic ware, Islamic copies of Chinese pottery and early Sgraffiato [decoration which is scratched through the clay surface coating to reveal the colour of the underlying clay].

Cities and Towns in East Africa, Fig. 2 The water facing side of Husuni Kubwa (Great Palace) in Kilwa Island

Cities and Towns in East Africa, Fig. 3 Port of Kilwa with recent Portuguese to man fort

Probably the largest earliest settlement of this period is that of Kilwa in Southern Tanzania (Figs. 2, 3, and 4). The settlement seems to have become a larger centre by about AD 1000 when the earliest stone structures could have been built (Chittick, 1974). Probably only a few stone structures would have been built then. The spectacular nature of Kilwa centre was the first to attract archaeologists in the 1950s. Mortimer Wheeler led a team of researchers in 1955 to conduct a test excavation. This research paved the way to more intensive archaeological researches by Neville Chittick, not only in Kilwa but also in other Swahili towns (Chittick, 1974, 1984).

Kilwa was large, the stone town itself estimated to have been about 50 ha in the early period. This settlement must have controlled other larger settlements of the area more economically, as settlements of a similar nature existed on the islands of Mafia, off the Rufiji Delta, and on the nearby island of Songo Mnara. Other settlements of the period related to the development of Kilwa are found in Zanzibar

Cities and Towns in East Africa, Fig. 4 Residential house around the Kilwa Friday mosque

and Pemba, the central coast of Tanzania, Comore and Northern Madagascar and on the northern coast of Mozambique and Zimbabwe. Archaeological work on sites located in those regions have yielded goods of exchange between these settlements, including coins, pottery and stone vessels, suggesting that Kilwa was a centre with economic influence if not direct control of the peer settlements north and south.

The early towns of Lamu Archipelago were excavated later by Chittick (1984) and Horton (1996). Settlements like Gedi, Malindi, and Mombasa grew to compete with those to the north and even Kilwa at the time when Portuguese had entered the region. What is obvious in the archaeology of the coast of Eastern Africa is that the Swahili towns were related, and this is true whether or not Kilwa controlled affairs in the whole region between AD 1000 and about AD 1400.

In the later phase, from about AD 1300, or slightly earlier, larger Swahili towns were built by coral stones and lime mortar and roofed by mangrove poles, lime mortar and palm leaves. Archaeology also finds a profusion of many smaller settlements, which were built by mud and wattle; the larger settlements may also have had the majority of its population living in such simple houses (Chami, 2002; Horton, 1996; Pradines, 2002). When ► Ibn Baṭṭūṭa visited the coast of East Africa in the AD 1330s, contrary to what archaeology suggests today, he did not see many stone houses even in larger towns such as Kilwa and Mombasa (Gibb, 1939). Whether this was a personal bias against stone houses if he only saw simpler town places is not yet properly explained (see discussion by Sutton, 1998).

It is also not quite certain whether each large Swahili town had its own trade and cultural link with foreign traders or if trade was only controlled by one or two larger towns which collected trade goods and distributed them to other towns. Ibn Baṭṭūṭa seems to have visited only two towns on the Swahili coast, Kilwa and Mombasa, suggesting that those were the larger ones. However, in the same time period a Chinese trip to East Africa led by ► Zheng He entered a town called 'Malin'. Some scholars think this place was Malindi on the Kenya coast (Chittick, 1975, p. 21; Wheatley, 1975, pp. 90–91); Fuwei (1996, p. 190) suggests that 'Malin' was Kilwa. A support for Fuwei comes from the fact that the wealthy clan at Kilwa at that time was known as Malindi and the most impressive tombs at the water front belong to this clan.

Probably each large town had its own trade abroad or a set of traders visiting particular ports in the Middle East and India. Archaeologists are now finding sites and many Swahili cultural materials in the Middle East, suggesting that the

Swahili people sailed to those distant lands (Sutton, 1998). It is likely that the profusion of foreign trade goods in all Swahili settlements could also suggest that individual towns engaged in long distant trade at least within the western Indian Ocean seaboard. This is testified by the fact that several towns are now known to have made their own coins and that when Vasco da Gama reached Northern Mozambique he had to get a person from Malindi, on the Kenya coast, to guide him to India. Probably the southern towns were not co-operating with the Portuguese.

The Origin of The Swahili Towns

Scholars had, up to the end of the twentieth century, debated the origin of the Swahili people and their stone town culture. Such debates revolved on the question of who the Swahili people were (Allen, 1974, 1983; Chami, 1994, 1998; Horton, 1987, Nurse & Spear, 1985; Pouwels, 1987). The original popular conception was that the Swahili people and their culture originated from the Middle East. These were alleged to have arrived in waves of immigration. Individuals in these waves founded settlements, which later grew into larger Swahili stone towns. Chittick (1974, 1975) used chronicles, particularly that of Kilwa, and archaeology to argue that the earliest immigrants could have arrived on the East African coast not earlier that the ninth century. This view suggested, therefore, that the Swahili people were originally Persians or Arabs who would later have mixed with Africans. Due to their alleged origin in the Muslim world the Swahili people were necessarily Muslims and people of towns.

Archaeologists such as Horton (1987), influenced by Allen (1983), suggested that the Swahili were people of Cushitic origin, from the northeast of Africa, who were originally pastoralists. The pastoralists, who are alleged to have ruled the Bantu speakers in a mythical land called Shunguaya, mixed with Bantu speakers, adopted Islam and spread to the rest of the coast and islands of East Africa. In this theory the Swahili people are seen as Africans who also mixed with the people of the Middle East in the process of adopting Islam and trade. This position was made more prominent in the 1990s (Abungu, 1994–1995; Horton, 1990; Sutton, 1994–1995) in an attempt to quash the discovery that the Swahili people were Africans of Bantu origin, people of the general region of Eastern and Southern Africa who were agriculturalists and fishermen.

That the Swahili people did speak a Bantu language was a point recognised by linguists from the 1980s (Nurse & Spear, 1985). Archaeologists had also established settlements of Early Iron Working people near the coast; scholars recognised that they were early Bantu speakers (Phillipson, 1977; Soper, 1971). Historians also recognised that the people reported by the Romans in the first centuries AD to have inhabited East Africa, then known as Azania, were agriculturalists and probably Bantu speaking (Casson, 1989). In the early 1990s this author suggested that the cultural tradition found in the earliest Swahili settlements was culturally related to that of the Early Iron Working tradition (Chami, 1994). In some cases settlements of the Early Iron Working people and those of the so-called early Swahili, termed by this author as Triangular Incised Ware tradition, were found in the same location. In some cases the later was found superimposed over the former in the offshore islands and on the coastal littoral of the central coast of Tanzania (Chami, 1998, 1999a).

The evidence of cultural continuity from the time of Christ, through the mid-first millennium AD, to the time of the foundation of the Swahili towns in the early centuries of the second millennium AD, has now been recognised by many scholars (Kusimba, 1999; Sinclair & Hakansson, 2000; Spear, 2000). Those who disagreed with the first set of evidence for this continuity have now revised their ideas (Horton, 1996; Horton & Middleton, 2000; Sutton, 1998). Archaeological findings now prove that the Swahili coast had been settled by an agricultural and trading population from the time of Pharaonic Egypt, 3,000 BCE, through the Greaco-Roman period (Chami, 2006). Whereas the former was of Neolithic tradition, the latter was an Early Iron

Working culture. Throughout these periods the Indian Ocean, just like it was during the time of Islam, had brisk trade with communities of Asia, the Middle East and the Red Sea/Mediterranean worlds. Ceramics and beads as evidence of trade of all these pre-Islamic trading periods have now been recovered from the islands of Zanzibar, Mafia, Kilwa and Rufiji River (for conspectus see Chami, 1999b, 2004, 2006).

The most recent thinking that the early Swahili people, or Zanj of the Arab documents, were Indonesians/Austronesians (Dick-Read, 2005) is an attempt to disregard the archaeological, linguistic and historical data already established. For this recent thinking to be regarded as scientific at least a discussion of the previous thinking on the subject matter and its flaws should have be debated.

Some Cultural Aspects of the Swahili Towns

General Culture

The culture of the Swahili towns, as already suggested, is African with an infusion of Islamic traits. It is these infused Islamic traits such as religion, law, language, writing and costume which have made many students of the Swahili culture identify the people as Arabs. The people who had adopted this culture themselves wanted to be identified as Arabs or Persians. However, ► Ibn Baṭṭūṭa identified the people as 'Sawahil' and the earliest European visitors to the Swahili world, the Portuguese, identified the people as 'Moors' or 'Suaili' as opposed to Arabs.

De Barros, as Ibn Baṭṭūṭa did, also identified the Sultans of Kilwa as black people (Chittick, 1975, p. 39). Barbosa, writing in about 1518, wrote, "Of the Moors there are some fair and some black, they are finely clad in many rich garments of gold and silk and cotton." To show that the Swahilis were different from Arabs, the Queen of Kilwa in the mid-eighteenth century wrote a letter calling home her people who had run away from the Arab/Omani domination of Kilwa to Mozambique. This was written in Kiswahili and not in Arabic; a Swahili letter suggesting that it was only the Europeans/Christians who were in conflict with the Arabs, but not the African/Swahili people (Omar & Frankl, 1994).

Religion

Most Swahili people are of the Sunni sect of Islam, which suggests an early link with Southern Arabia. Large mosques (Fig. 5) had been built with stones from AD 1,300 or slightly earlier in every town of the Swahili coast. Some towns have several mosques, some being smaller for the purpose of a clan or a family. Kiblas/the north of these mosques were elaborately made; probably the one at Songo Mnara in Kilwa (Fig. 3) is the most elaborate of those seen by this author. One very unique religious aspect of the Swahili towns is that of making spectacular burials for the dead. The tombs, which most of them concentrate around the mosques, were built using stones and lime. Walls of some are more than 2 m high with various decorative panels including impressed Chinese porcelain. Some tombs have high standing pillars some reaching up to six meters above the tomb.

These aspects of tombs are non-Islamic as they are found nowhere else in the Muslim world. Muslim burials are supposed to be made humbly and no materials or aspect of wealth are supposed to be involved. That these spectacular tombs are also found attached to houses or are located in compounds where people were living suggests that this is an African culture blended with Islam. I have noted elsewhere (Chami, 2002) that the African tradition of wanting to live with the spirit of the dead in the same house/compound or within the settled landscape is the one portrayed in this context. Like the ancient Egyptian tradition, the spirit should not be abandoned in the wilderness away from human warmth and food. A failure to observe this rule was/is expected to bring bad omen to the family.

Writing and Arithmetic

Whatever type of pre-Islamic writing that could have existed on the coast of East Africa cannot be known for now. Early Islamic characters found on the Swahili settlements are Kuffic, the earliest

Cities and Towns in East Africa, Fig. 5 Kilwa Friday mosque

known being of the eleventh century tomb of Kizimkazi in Zanzibar (Flury, 1921). Later on Arabic scripts were used to write in the Swahili language. These can be seen in many tombs post dating AD 1300.

In daily counting the Swahili people mixed African and Arabic words. Counting may have followed Arabic languages in schools or official places, but in normal cases African counting was used. Today most counting words in Kiswahili are still African with the exception of a few numbers such as 20, 30, 40 and 50, which are in Arabic. Probably much more Arabic influence came after the rule of the Omanis from AD 1884.

Architecture

Garlake (1966) studied the architecture of the Swahili towns; his interpretation of Swahili architecture has prevailed (Chittick, 1984; Sutton, 1998). As was noted with the tombs, the architecture of the Swahili buildings is of Western Indian Ocean Seaboard origin. It is the tradition that began and evolved within the region. The architecture is very much conditioned by available resources for building lime coral rubble which is made into walls with lime mortar and then plastered with the same mortar. Rarely were bricks and dressed stones (apart from porites) used. The only dressed stone used for door and window frames, mihrabs [a niche in the wall of a mosque or a room in the mosque that indicates the direction of Mecca] and lamp chambers was porite [coral]. This is a coral cut from underwater while fresh and it is dressed and decorated or inscribed while fresh.

For multi-storey houses floor slabs were made by arranging mangrove or other hard woods across. Lime mortar, sometimes mixed with coral rubble, was spread on top. Some houses, especially mosques, had moulded roofs with decorative arches, domes and vaults. Most houses must have been roofed by wood and palm/grass. Swahili houses had large verandas and corridors for relaxation and cooking. Carved panels decorated the doorframes.

Livelihood

Swahili people engaged in various economic activities. They are traditionally agricultural. They lived in mostly settled communities with vegetable gardens around their compounds and in areas a few hours' walk from towns. Allen (1983) characterized the Swahili as people who commute from town to the countryside for agricultural purposes. This has been the situation from ancient times. Crops cultivated include rice, millet, beans/peas, banana, coconut, sugar cane, spices and fruits such as mango and oranges. In recent history American crops such as maize,

cassava, sweet potato and tobacco have been added to the list.

The Swahili people would have been mixed farmers who would also have domesticated chicken, cattle and ovicaprids (sheep and goats). These are well authenticated from archaeological records dating back to the early Swahili period. They also had dogs and cats and for the northern coast donkeys and camels. Due to environmental variability the northern part of the Swahili coast would have been more pastoral than the south because of the interaction that existed with the nomadic regions of Somalia and Northern Kenya.

Fishing must have dominated the activity of those living near the shore and on the island settlements as it secured the most reliable means of obtaining protein. They fished in the deep and shallower, waters and there is much evidence for times when they consumed a lot of shellfish probably suggesting difficult times (Msemwa, 1994). There was also fresh water fishing. There are several large rivers entering the Swahili coast from the deep interior and also few lakes near the littoral which provided fish. Salting and drying fish facilitated transport to the deep interior.

Sailing, not only for fishing, but also for trade was probably the most prestigious activity of the Swahili man. Swahili towns consisted of people who had travelled far for the purpose of trade or prayers. There was a lot of intermarriage between communities. The Swahili people can therefore be seen as a maritime people. Goods to be exchanged with those arriving from abroad had to be collected from the south or interior of the region and this also involved distribution of those imported goods. So the Swahili towns were trade axes providing for the larger part of Eastern and Southern Africa.

Consequently the Swahili people were also involved in building sailing vessels. The Romans found the people of the Swahili coast already making sewn boats and also importing boats from abroad (Casson, 1989). This technology grew tremendously and by the time of the stone towns the Swahili people must have been building large dhows used to cross the Indian Ocean to Arabia and India. In most of the Swahili towns today one can find at least one operating dhow/boat building yard, suggesting a continued tradition. Related to this technology was that of metal working, which has passed down since ancient times. This technology was necessary for cultivation and boat making, as wood had to be felled and worked.

C

Swahili Towns in Ruins

It was noted earlier that the realm of the Swahili culture is in the period between AD 1200 and 1500. After this heyday the Swahili culture entered into a deteriorating moment following the penetration of Europeans into East Africa. They wanted to conquer by destroying the large Swahili towns such as Kilwa and divert trade to the Atlantic Ocean towards Europe. The monopoly of trade was taken from the Swahili traders and put into the hands of European companies and later on, after 1800, into the hands of Oman Arabs and Indians. The Omanis came to East Africa to challenge the Portuguese. It was the Swahili rulers who invited the Omanis to use their Muslim responsibility to assist Muslim brethrens, but the Omanis did not leave after they accomplished the task. Only petty trade was left in the hands of the Swahili. In some towns trade was left to the Swahili people, but they had to cater for the masters of the new order.

In the new order, the Swahili towns, which had not given way to invaders before, were suppressed to the extent that they fell into ruins. This was necessary because other prosperous settlements, mostly controlled by the new Portuguese and Omani powers, emerged and it is here the new elite, whether foreign or local, would move (Chami et al., 2004). As Kilwa and other settlements of its type decayed, with only short periods of renewal, previously unknown towns emerged from about 1700. Such towns included Zanzibar, Bagamoyo and Kilwa Kivinje. Mombasa also grew substantially. These are towns founded by the enterprising British and German colonials. From the 1890s the new colonial towns such as Dar-es-Salaam, Nairobi and Kampala challenged these other towns. See (Chami et al.)

for an explanation of the fall and the rise of the Swahili towns.

See Also

- ► Agriculture in Africa
- ► Beads
- ► Ceramics: Mimbres Pottery
- ► Navigation in Africa

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Cities and Towns in West Africa

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West Africa, like most regions of the continent, is still largely rural. Even after decades of rapid urban growth and the emergence of cities of one million people or more, the majority of the population continues to live in rural areas. However, cities and towns generate higher revenues than the countryside. Urbanisation has brought major changes for both urban and rural dwellers. Large cities, which are often ports, are gateways to the rest of the world. The most traditional practices coexist with the most advanced technology and, in contrast to the negative image conveyed by media about the Developed World, Africans have shown a strong ability to adapt to the global world (see Fig. 1). That said development in West Africa is impeded by a number of problems. This article will address the endogenous and exogenous factors hampering urban development in West Africa. First, we will show that the (long) urban history of West Africa is the result both of indigenous and European influences. Then we will analyse recent urbanisation trends from a demographic point of view before examining the origin and reasons for urban development. Finally we will consider the issue of urban management. For the purposes of this article, "West Africa" is defined as the countries to the west of the line running from Lake Chad to the border between Nigeria and Cameroon.

A Long but Little-Known Urban History

Urbanisation is not only a contemporary phenomenon in West Africa. Urban centres have developed in this region of the world for over 2,000 years (Coquery, 1990). In the Middle Ages, some were very prosperous and were known by Europeans as great cultural and commercial places (Timbuktu, for instance). Some were even compared by travellers to European cities such as Amsterdam or Lisbon (Benin City in the seventeenth century).

Still, the history of West African towns and cities is still very incomplete, mainly because this is a new field of research. Urban Africa was only 'discovered' by historians in the late 1970s and until very recently there has been little interest in pre-colonial urbanism other than through the work of archaeologists (Anderson & Rathbone, 2000). The scarcity of written sources and the fact that few stone monuments survive may explain why African urban history is still very incomplete. For a long time, towns and cities were only presented as colonial creations. Earlier settlements were not recognised as urban because their features were not similar to those of European towns and cities (often considered as a standard to define urban settlements): there were no stones used in architecture, an abundance of agriculture, and very low population density. But recent research has shown that West Africa has nurtured various forms of settlements quite distinct from simple villages long before the Europeans' arrival.

The first urban settlements in West Africa, as in the rest of the continent, were indigenous creations (Coquery, 1990). The most ancient is Jenne-Jeno (distinct from Djenne), located in Middle-Niger, discovered by archaeologists in 1977 (For more information and to see pictures of the archaeological site, see: www.ruf.rice.edu/~anth/arch/brochure/). It was probably created around 250 BCE, reached its peak between 750 and 1150, declined under Islamic influence and finally disappeared in the fifteenth century. Except for the fact that it had city walls, Jenne-Jeno did not look like a medieval European city. It was quite extended (40 ha around the tenth century), as opposed to very dense European settlements of the same period. There were no monuments in the centre of the city (such as palaces, churches or markets always present in

Cities and Towns in West Africa, Fig. 1 Cotonou, Bénin. Tall, modern buildings are proudly erected next to very crowded places where the informal sector is blooming and *yellow* and *green* taxis are waiting clients to transport goods. Note the mobile phone antenna and the satellite dish on *top* of the *blue* building; all their offices are connected to the Internet. Some investors are less successful, as can be seen from the unfinished building on the *right* (© Franck Houndegla)

European towns and cities). And the buildings were made of adobe. But Jenne-Jeno was an important commercial centre for its region (fishing and agricultural products) and it was also probably one of the first places of the trans-Saharan trade (salt against copper in the fourth century).

Other towns and cities developed in this region of contact between the Sahara and the Savannah (Fig. 2), where international trade was possible. In the Middle Ages, the succession of great centralised states (ancient Ghana (Ancient Ghana's territory is distinct from contemporary Ghana. It broadly covered the oriental Senegal and Mauritania, the occidental Mali and a part of the current Guinea. The creation date of the Ghana Empire is not precisely known, though an Arab writer mentions it in the eighth century. It finally disappeared in the twelfth century), Mali and Songhaï empires) contributed to the development of a network of towns and cities, among which Timbuktu, Djenne and Gao are the most famous. Following the trade Saharan routes, the Islamic and Arabic influences grew in the process of urbanisation. The introduction of Islam gave to the great cities mentioned above their monuments: Sudanese style mosques (Fig. 3). It also gave them a cultural aura (Timbuktu was a famous Islamic intellectual centre). And it played a role in matters of social organization; these cities were cosmopolitan places. Whatever the influence of Islam, their fame in the European Middle Ages is mainly due to the fact that they were the gold providers for the East through the trans-Saharan trade (See a map: www.metmuseum.org/toah/hd/gold/hg_d_gold_d1map.htm). But they also played an important role in the economy and even in the urbanisation process of southern regions of West Africa. Stopover places, first created to facilitate the exportation of gold and other goods from coastal regions, progressively turned into real towns, such as Begho

Cities and Towns in West Africa, Fig. 2 The city of Timbuktu: a place of contact between the Sahara and Sub-saharan Africa (Source: www.sum.uio.no/timbuktu/)

Cities and Towns in West Africa, Fig. 3 Djenné, Mali. This town exemplifies early urbanization in West Africa. Situated on the Bani River, Djenné dates back to 250 BCE In the thirteenth century, Djenné was an important market for trans-Saharan trade, particularly between North and West Africa. The most common items of exchange were gold, slaves and salt. Djenné also became an important center for Muslim learning during the seventeenth century. The city's mosque (at the rear of the Fig.) is the largest mud-brick building in the world (© IRD – Jacques Champaud)

Cities and Towns in West Africa, Fig. 4 Kano, Nigeria. The old-walled section of Kano is nearly 1,000 years old and is enclosed by a mud wall. Located on the edge of the Sahel, Kano is a Muslim city, one of the oldest in West Africa. Kano was the centre of a prosperous Hausa city-state in the seventeenth century, when the Songhaï Empire declined. Under the Sokoto Empire (nineteenth century), it became a very important place of textile production in West Africa. At the end of the nineteenth century, half of the West Sudanese population was dressed with loincloths from Kano (Source: www.uni.edu/gai/Nigeria/Pictures/kano.html)

(The Dioula merchants were also the actors through which the Sudanese-style mosques spread all over West Africa).

Trade, through trans-Saharan routes, was a major factor of urbanisation in medieval West Africa. However it is worth noting that some great urban regions also developed in West Africa, even if they had weak connections with this trade system. It seems to be the case for the Hausa-speaking city-states, the Yoruba towns or the Ghanaian urban system. These urban regions have some common features. They started their development in the Middle Ages and were especially prosperous between the fifteenth and the eighteenth century (their respective peak periods are however not totally contemporaneous). In contrast with the Middle Niger cities, the towns of each of these regions emerged without a centralised state. They shared a common culture (language, religion, social organisation) but they were in competition, and sometimes at war, each one of them trying to extend its influence on the surrounding countries (Fig. 4). Whereas the Middle Niger cities were mainly turned towards international trade, the towns and cities of the Hausa, Yoruba and Ghanaian regions were first engaged in regional trade. Agriculture was sufficiently intensive to produce enough surplus to feed an important urban population. In Ghana for instance, around 30 % of the population lived in urban areas and 70 % of the urbanites (merchants, craftsmen, the nobility and their families) bought their food in markets (Coquery-Vidrovitch, 1993). The rural people were under the domination of urban power; they were sometimes forced to leave their villages in order to settle in the towns (Yoruba region) and also paid important taxes. In the Ghanaian region, rural taxes represented between a quarter and a half of peasants' earnings (Coquery-Vidrovitch). Some cities of these three regions remained famous: Kano and Katsina in the Hausa region, Great Accra in Ghana, Benin City, Old Oyo or Ife in the Yoruba area. They have been described by the first Europeans who arrived in West Africa (Iberian sailors) in the fifteenth century. Till the eighteenth century, Ghanaian and Yoruba towns and cities (Hausa city-states were less influenced because they were far from the coast) benefited from the new forms of trade introduced by

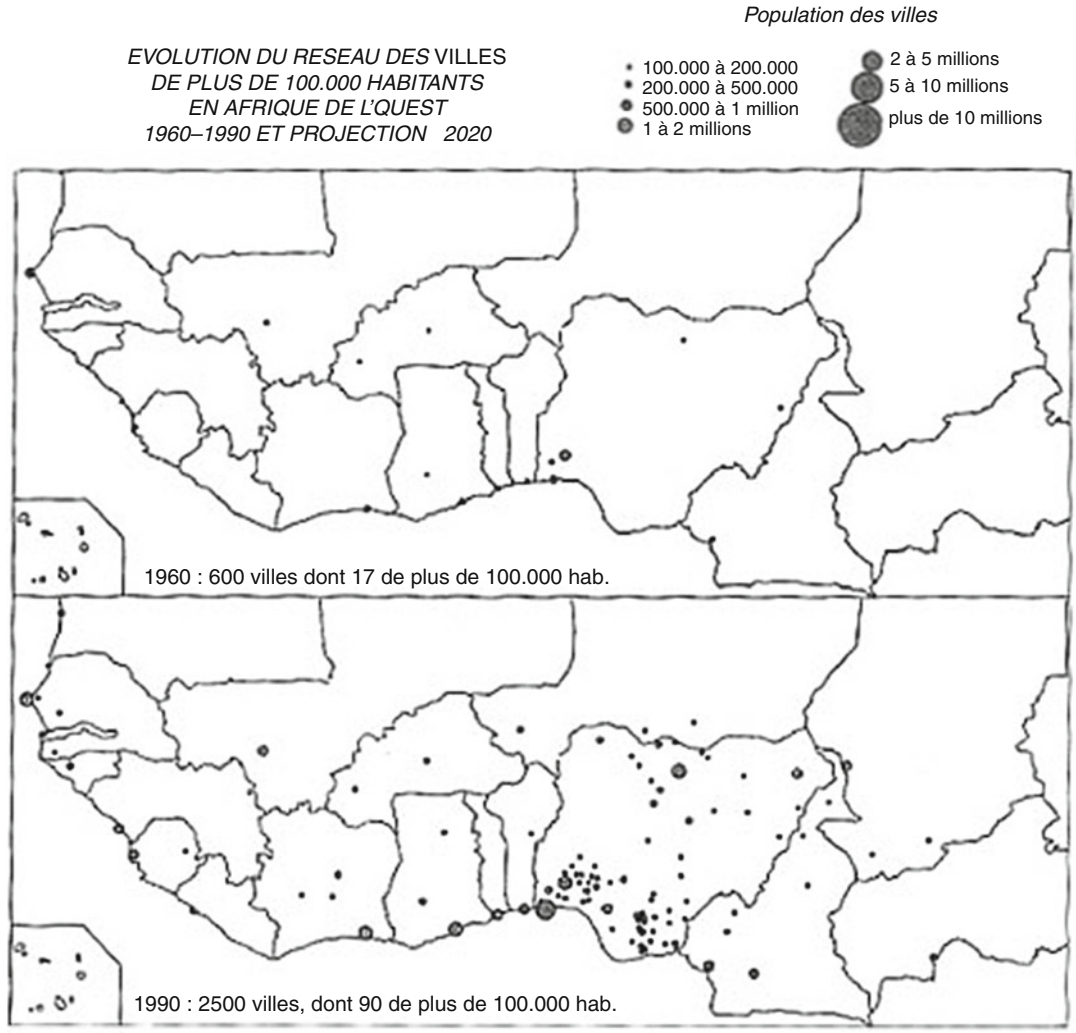
Cities and Towns in West Africa, Fig. 5 Gorée, Senegal. This building, built around 1780, may have been the last slaves' house in Goree. The first ones dated back to 1536, built by the Portuguese, first Europeans to set foot on the island in 1444 (Source: www.globalgeografia.com/album/senegal/goree.jpg)

Europeans. But the launching of the slave trade disrupted these urban networks.

The first European settlements in West Africa were not towns: they were only isolated forts on the coast, whose purpose was to resupply the shipping expeditions. They progressively turned into trading posts and finally into small towns when the slave trade was introduced in the eighteenth century (Fig. 5). Gorée, Saint-Louis or Ouidah, for example, were central places at this time. They were inhabited not only by Europeans but also by African people. And a kind of local bourgeoisie, with a Creole culture, appeared. The overseas trade acted as a new vector of indigenous urbanisation on the coast and also in the hinterland. New states, engaged in the slave trade, emerged and gave birth to new capital cities (kingdoms of Porto Novo and Abomey, Ashanti Empire). For instance, Kumassi, the Ashanti capital city, was a center of the slave economy, but it was also a trade centre for kola nuts, which were exported to the north. It was the heart of a dense road network, quite far from the coast, in order to escape a too strong European influence. There were 77 neighbourhoods (around 13,000 inhabitants in 1870) separated by large and rectilinear avenues. It remains today an important city in Ghana.

The abolition of slavery, declared in 1815 in all European countries, appears as a shock in African urban history. The cities whose prosperity relied on the Atlantic slave trade declined. New settlements were created to welcome freed slaves from the United States (Monrovia) or from the British territories (Freetown). Some existing towns turned the end of the Atlantic trade to their advantage by using for their own development the workforce of the slaves. For instance, Kano became a great centre of textile production in West Africa (Fig. 4). In 1894, there were 100,000 inhabitants, 50 % of whom were slaves. During the nineteenth century, various urban centres emerged as commercial places and/or as capital cities for new West African states (Sikasso, capital city of Kenedougou; Sokoto, capital city of the Fulbe Empire…).

To sum up, it should be clear that the urban history of West Africa started before European colonisation. First contacts with Europeans, from the fifteenth to the nineteenth century, had an impact on the urbanisation process, but they did not totally drive it. When Europeans started to colonise West Africa, they created new cities, mainly ports (e.g., Dakar, Abidjan, Cotonou, Conakry…) and crossroads places (e.g., Bamako) aimed at facilitating natural resources exportation (see Map 1). They also took advantage of the existing urban networks. Indigenous towns and cities happened to be excellent places for the political and economic control of the territories. Colonisation seriously boosted the urbanisation process by creating new urban activities. Labour migration was an important factor in urban development in colonial times when



Cities and Towns in West Africa, Map. 1 Evolution of the West African urban system (1960–1990). 1960: 600 towns and cities, 17 have more than 100,000 inhabitants. 1990: 2,500 towns and cities, 90 have more than 100,000 inhabitants (Source: www.urbanisme.equipement.gouv.fr/cdu/datas/docs/ouvr16/2020_p1.htm). These maps show the proliferation of towns in West Africa during the second half of the twentieth century. Most of the larger towns and cities were developed under colonial rule and were founded in coastal regions and along rivers

workers were needed for public infrastructure (airstrips, railways and ports), administration (soldiers, clerks) or various private services (maids, etc.). Migration flows to urban centres continued after independence. In sum, colonisation acted as a starter for urban development on a larger scale (Bairoch (1985) estimates that the urbanisation level in Africa as a whole was 5 % in 1900, 12 % in 1950, and 28 % in 1980).

Recent Urban Trends in West Africa: Rapid Demographic Change

In terms of the contemporary urbanisation process, West Africa is at once lagging behind (with the exception of Nigeria, it remains one of the least urbanised regions of the world) and at the forefront of change (the region had one of the highest urban growth rates of the second

half of the twentieth century). Urban growth has not been linear: after a peak in the 1960s (9.3 % per year for West Africa as a whole), it reached a low of 5.6 % in 1990–2000 (Fig. 3), and the region remains predominantly rural (see "Extra 1 Inconsistent Definitions and Measures Vagaries"). Migration is usually seen as the main contributing factor in the growth of towns and cities. According to a 1988 UN report, almost all governments of developing countries believed that internal rural-to-urban migration was the dominant factor contributing to the growth of cities (United Nations, 1998). But urban growth can be generated by any of three mechanisms: natural growth, reclassification and migration. All these components follow a specific pattern in the context of West Africa.

Natural urban growth (i.e., the surplus of births over deaths) in West Africa remains one of the highest in the world: 2.7 % annually, versus 1.9 % for the developing world as a whole (PRB, 2001). (Natural growth rates are nevertheless lower in urban than in rural areas, since mortality and fertility have declined faster in towns and cities than in the countryside). This is one reason why urban growth remains so high in this region compared to the rest of the world. A United Nations study has shown that the contribution of natural growth to urban growth is much higher in Africa than in other parts of the world. On the African continent, natural growth accounted for 75 % of urban growth in the 1980s, compared with a share of only 50 % in Asia, excluding China (Chen et al., 1998) (Fig. 6).

Another feature of urban growth specific to West Africa is the importance of reclassification. Reclassified settlements are those that cross a population threshold (10,000 inhabitants in the GEOPOLIS database used in this article; see "Extra 1 Inconsistent Definitions and Measures Vagaries"), beyond which they are considered urban instead of rural. These newly-urban settlements contribute to urban population growth, even though their population may not have moved. In Africa as a whole, between 1950 and 1980, the share of reclassification in urban population growth was 26.4 %. This means that, in 1980, more than one new African urban dweller in four lived in an agglomeration that had been classified as rural in the previous 30 years. This rate was only 13.4 % worldwide, excluding China and Korea for which reliable data are not available (Moriconi-Ebrard, 1994). Thus, urban growth in Africa, much more than in the other continents, is due to the proliferation of new small urban centres that had previously been considered rural (see "Extra 2 The Urban Future: Mega-Cities or Small Towns?").

Cities and Towns in West Africa, Fig. 6 A street restaurant in Dakar, Senegal. Women prepare and sell traditional dishes (rice on the *left* and vegetables on the *right*) (© IRD – Michel Dukhan)

Considering the foregoing arguments, the role of migration in urban growth seems to be less important than is commonly assumed. The process of urbanisation, from a demographic point of view, is more complex than a simple rush of migrants from rural to urban areas. Furthermore, the contribution of migration and reclassification to urban growth appears to be decreasing. Indeed,

according to the GEOPOLIS database, two-thirds of urban growth in West Africa was due to migration and reclassification in the 1960s, versus only one-third in the 1990s (Bocquier & Traoré, 2000). This result is consistent with several other studies (Arnaud, 1998; Chen et al., 1998). To what factor can this change be attributed?

One reason is mathematical. Urban growth due to migration automatically falls as the urban population increases in relation to the rural population, simply because the rural population who could potentially leave their villages becomes smaller. When the majority of people live in villages, net out-migration (i.e., a negative migratory balance) from a rural area means, for the same volume of migrants, a higher net in-migration rate towards urban areas. As the respective proportions of the rural and urban populations balance out, the number of migrants who contribute to urban growth decreases, even though the probability of out-migration from rural areas may remain the same. This is what happens in developed countries; when more than 60 % of the population lives in urban areas, urban growth by immigration from rural areas is necessarily low. But is this mathematical equation sufficient to explain the decline in urban growth in the 1980s and 1990s in Africa, where the level of urbanisation is only around 30 %?

In fact, the decreasing role of migration in urban growth is largely due to new migratory trends. In sub-Saharan Africa as a whole, several recent sources indicate that rural out-migration has not only subsided, but that its counter-stream (i.e. urban out-migration) has increased. West Africa offers interesting examples in this regard. Côte d'Ivoire, for instance, experienced a migratory reversal between the mid-1980s and the late 1990s (Internal migration has probably evolved since then, due to civil war); urban-to-rural migration exceeded the opposite flow, causing the level of urbanisation to decline (Beauchemin, 2002b). Even though the counter-urbanisation process is still marginal in Africa at national level (Zambia is the only other country where this trend has been identified), many countries are experiencing a decrease in rural-to-urban migration to some extent. A West African network of national migration surveys revealed that secondary towns in seven countries (Burkina Faso, Côte d'Ivoire, Guinea, Mali, Mauritania, Niger and Senegal) recorded a net loss of migrants between 1988 and 1992 (Bocquier & Traoré, 2000). Some larger cities are also affected by a decline in migration; Accra, capital city of Ghana, apparently saw significant net out-migration in the mid 1980s (Simon, 1997); and Abidjan had no migratory growth between 1988 and 1992, excluding international flows (Beauchemin, 2001). Economic decline appears a pervasive explanation for the slowing of urban growth and change in migratory trends. Despite these new migratory patterns, in most West African countries, the urban population continues to grow faster than the rural population. However, due to the slowdown in urban growth, the rural way of life could well remain predominant in West Africa for a long time to come (Bocquier, 2003).

The Economic Roots of Urban Development

Although urbanisation is commonly associated with a gradual reallocation of labour from agriculture to industry, which is what happened in the industrialised world in the nineteenth century (Bairoch, 1985), urban in-migration in West Africa occurred (and continues to occur) without industrial development. In addition, African countries witnessed a massive migration of the rural population to urban areas despite rising levels of urban unemployment and underemployment (Todaro, 1997).

These apparent contradictions in migration and urbanisation were initially attributed to irrational behaviour. A better explanation was found in the concept of economic dualism between the formal and informal urban sectors, first introduced by Lewis (1954) and extended by Todaro (1976). In contrast to the formal sector (geared towards capital-intensive, large-scale modern production), the informal sector is a traditional, unregistered, subsistence sector geared towards labour-intensive, small-scale production.

Cities and Towns in West Africa, Fig. 7 A barbershop in Ouagadougou, Burkina Faso. Female hairdressers usually work at home (© IRD – Marie-Noëlle Favier)

Cities and Towns in West Africa, Fig. 8 Abidjan, Côte d'Ivoire. Informal economic activities range from itinerant micro-commerce to established activities (joinery, garage mechanic. . .). Here young girls sell plastic bags of fresh water, carried on their head in large baskets (© IRD – Philippe Haeringer)

However, the spectrum of informal activities ranges from the so far predominantly downmarket informal sector to an upmarket informal sector (see Figs. 7 and 8), which is closer to small and medium business type activity, even though it does not comply fully with tax and social security regulations. The existence of the informal sector explains why rural-to-urban migration has persisted-leading to rapid urban growth-despite limited absorption capacity in the urban formal employment sector (see "Extra 3 Migration, Urbanisation and Development: A Controversial Issue"). Although sometimes discouraged by public authorities because of its illegality and suspected tax evasion, most researchers now recognise that the informal sector has economic advantages; it absorbs surplus labour and provides a safety net in a context of high unemployment and poverty (Becker, Hamer, & Morrison, 1994; Snrech, 1994). In fact, the sector employs the majority of urban workers and serves the purpose of receiving and integrating migrants and providing them with minimum subsistence. However, this pattern has evolved in the last two decades as a result of the economic crisis.

Since the 1970s, West Africa, still mostly dependent on commodity exports (coffee, cocoa, bananas, petroleum, etc.), has suffered from falling prices on international markets. West African countries first delayed the crisis by maintaining public expenditure. But, as debt became unsustainable, structural adjustment programmes (SAPs) imposed by international organisations and donors focussed on reducing

public expenditure via privatisation and staff redundancies (Duruflé, 1988; Becker et al., 1994). Employment surveys conducted in 2001–2002 showed that public sector employment in seven West African capital cities was 8 % on average, with a higher-than-average rate in Niamey (15 %) and Ouagadougou (13 %), which is still rather low considering that these cities concentrate most of the public sector activities (AFRISTAT, 2005). In the 1990s, urban unemployment reached unprecedented levels, in particular among educated people looking for jobs in the formal sector (Bocquier & Le Grand, 1998; Charmes, 1996; Lachaud, 1994). In 2001–2002, in Cotonou, Bamako and Lome unemployment was relatively low (5–8 %) compared with Dakar (12 %), Niamey (13 %), Abidjan (14 %) and Ouagadougou (15 %) (AFRISTAT, 2005). These figures, computed using the ILO's standard measure of unemployment, would be much higher if they included discouraged unemployed city dwellers (i.e. non-working people who have stopped looking for a job after unsuccessful attempts) and 'underemployed' people. Gugler generally defines 'underemployment' as the underutilisation of labour. This occurs when workers are so numerous that at all times a substantial proportion is employed part-time. It is linked to the economic role of solidarity groups that continue to employ all their members rather than laying them off when there is insufficient work to keep them fully occupied (Gugler, 1982). As most workers turned to the informal sector, the crisis caused the informalisation of the urban economy. In West African capital cities (Cotonou, Bamako, Lome, Dakar, Niamey, Abidjan and Ouagadougou), about 75 % of employment is informal, with little variation (plus or minus 5 %) between countries. However, the informal sector itself suffered from worsening economic conditions. Demand from urban households plummeted as standards of living deteriorated. In 2001–2002, more than 55 % of workers earned less than the official minimum hourly wage, and average monthly household income ranged from $30 to $70 (i.e. $10 a month per urban dweller on average) across the seven capital cities listed above. Less income in the informal sector is shared by more people as competition was heightened by the arrival of those left out of the formal economy (Arnaud, 1998). Urban poverty has increased dramatically in West African towns and cities. Even though the recession affected both urban and rural areas in West Africa, urbanites seem to have suffered more hardship than their rural counterparts. Jamal and Weeks calculated that, in the 1970s and 1980s, the rural-urban income gap in many African countries either disappeared or shifted in favour of the farmers (Jamal & Weeks, 1993). The fall in real urban incomes has generated a new urban poor population, who are forced to adopt survival strategies. Households diversify their sources of income; previously non-working members, mainly women, enter the petty commodity sector, and wage earners take on supplementary cash-earning activities. They reduce their expenditure by developing subsistence agriculture within and around the urban area (see Fig. 9), and by adjusting their housing arrangements (some move towards less expensive districts, while others rent out a part of their house). Another coping strategy is to strengthen and adapt rural-urban ties, which includes returning to rural homes. This often involves changes in household composition. Adult members are sent to villages to diversify income in order to cope better with economic hazards, some children are sent back to rural areas where schools are cheaper, while foster children are sent back to their original households (Beauchemin & Bocquier, 2004; Potts, 1997). These strategies are not marginal and explain why urban out-migration has increased significantly in West Africa.

Household coping strategies would appear to be effective in adapting to the deteriorating urban economy. In West Africa, no riots broke out in response to the implementation of structural adjustment. However, in this context of rising poverty, social and ethnic tensions have been exacerbated in some countries (On the conflict in Côte d'Ivoire, see Beauchemin, 2005). In other countries, remittances from international migrants might have acted as safety valves. For instance, Senegalese and Malian emigrants are

Cities and Towns in West Africa, Fig. 9 In a context of growing poverty, urban households turn to agriculture within and around urban areas in order to reduce their expenditures. Here, the Figure also shows the progressive building process in West Africa. Construction is usually incremental due to the underdeveloped nature of the housing finance system sector. Therefore, people build as they get money (© IRD – Philippe Haeringer)

known to play an important role in both rural and urban development in their home countries (Bertrand, 1994; Gueye, 2002; Tall, 1994).

Construction of Towns and Cities

The physical appearance of West African cities and towns is mostly the result of a recent and rapid pace of growth, which public authorities, despite their intentions, have been unable to control. Almost everywhere, governments nationalised land after independence, and public authorities were supposed to become the main-if not the only-actor in urban development. They did indeed draw plans and build housing units to supply demand from urban residents. However, the supply of public housing has only ever met a small proportion of needs, and the dwellings or serviced plots made available are not affordable for the lowest income groups. How did the others-in fact the majority-find accommodation? They relied on the informal sector, by buying a plot from a holder of customary tenure rights and building their own houses, or by renting a place in an unauthorised neighbourhood (Durand-Lasserve, 1986; Rakodi, 1997).

As in other sub-Saharan African countries, in West Africa there are overlapping land tenure systems. Although the law imposed public control over land, the customary system has survived informally. Theoretically, in that system, land cannot be owned as private property. It is vested in a community (usually a lineage whose ancestors settled on the land), and administered by the head of the group. In that system, unused land can be allocated to a non-member of the group, especially if he needs it to survive. In that case, in the traditional system, only a token payment to the land chief is required. This is not a sale since the land remains theoretically inalienable. However, in urban areas, as pressures intensify, traditional payments are moving closer to real land prices. Since the 1960s, in all cities, customary authorities have informally sold (i.e. without transfer of title) land for urban development. Since the occupants have no title, public authorities can always contest the use to which the land is put. Until the late 1970s, informal settlements were demolished. Then policies switched to regularisation and upgrading programmes; titles or occupancy licences were delivered to the previously unauthorised occupants and infrastructure was installed (Amis, 1989). All in all, states now tolerate informal settlements because they meet popular demand. Building a house is for most households the only source and accessible investment while bank savings are unreliable and poorly profitable. The informal land tenure system has thus become more secure. In 2001–2002, between 50 % and 85 % of self-declared landowners in seven West African capital cities possessed a land title (AFRISTAT, 2005). The urban structure

Cities and Towns in West Africa, Fig. 10 Dakar, Senegal. This neighbourhood is next to the airport area (rear of the Fig.). It was officially declared unsuitable for building development by the Senegalese government. However, this land was sold for construction by customary authorities of the *Lebou* (a local ethnic group). The quality of the houses shows quite well that unauthorized areas do not necessarily become slums. Nowadays, this type of neighbourhood is often regularized after construction (informal owners finally obtain titles from the public authorities) (© IRD – Michel Dukhan)

of unauthorised neighbourhoods is also quite similar to that of regular districts; landowners, intermediaries and buyers are adopting urban and architectural standards likely to facilitate subsequent regularization (see Fig. 10).

In West African cities, the majority of houses in both the formal and informal sectors have been built on an individual rather than mass production basis. The typical West African housing unit is the compound house (see Fig. 11). This type of accommodation houses 85 % of the population in Abidjan (Côte d'Ivoire) and Bamako (Mali) and three-quarters of households in Accra (Ghana). Even in informal areas, urbanites do not build their own houses; artisan builders are commissioned (Coquery, 1990). Construction is usually incremental, mainly due to the lack of title and an underdeveloped housing finance sector (see Fig. 9). According to needs and means, houses are extended horizontally (by filling empty spaces with new rooms, such as by reducing courtyards to corridors) or vertically (by adding more storeys). Most compound houses are permanent structures, built of cement breezeblocks with corrugated iron roofs. Mostly built for rental, compounds usually accommodate several families and various socio-economic and ethnic groups, enabling a mix of the city's population groups and cultures (see Fig. 12). Compared with other cities in the developing world, including the rest of sub-Saharan Africa, most West African cities do not appear to be very segregated, either socially or ethnically.

The informal nature of land distribution and housing production has led to under-serviced urban development. There is no legislation governing construction in unplanned housing areas, and consequently there is no tax on the

Cities and Towns in West Africa, Fig. 11 Abidjan, Côte d'Ivoire. Except in the downtown center and in some upper-class districts, the city skyline is very low and horizontal. 85 % of the Abidjan population lives in compounds such as this. Several households surround the courtyard, usually the center of the plot. Each living unit normally comprises one room or two rooms of approximately 10 m^2, one which is used as a bedroom and the other a sitting room. Three rooms is the maximum number of rooms for this type of housing and that is very rare. Courtyards are progressively filled with new constructions. At the rear, owners have started to build additional storeys (© IRD – Philippe Haeringer)

capital gain on land sales and no obligation to service land prior to sale. As for housing, publicly provided services and infrastructure have lagged far behind needs. As a result, a large share of the urban population does not have access to basic services. Access to water, vital for health, is a concern for much of the urban population (see Fig. 13); in 2001–2002, only 43 % of all households had access to tap water in the seven capital cities cited above, with the proportion ranging from about one-quarter in Lome, Bamako and Niamey to 41 % in Cotonou, 50 % in Abidjan and 68 % in Dakar (AFRISTAT, 2005).

In response to service shortages, urban dwellers have adopted a range of alternative strategies. In Pikine, the largest suburb of Dakar, by taking advantage of political clientelism, residents in the unauthorised area have obtained as many facilities (schools, health centres, water points) as their counterparts in the formal area. For urban dwellers, political pressure has become a potentially powerful lever since decentralisation in the mid-1980s. Do-it-yourself is another strategy; illegal hook-ups to electricity may be a way to access power (Marlard et al., 1999). Informal economic activities have also emerged to compensate for the inadequacy of the public service system. Many people rely on private vendors instead of collecting and queuing themselves for water although prices are more expensive than for public supplies (see Fig. 14). Collective taxis and private minibuses (*gbaka* in Abidjan, *cars rapides* in Dakar, etc.) serve the neighbourhoods with terraced roads bypassed by public transport systems and are usually less expensive (see Fig. 15). A large proportion of the residents of

Cities and Towns in West Africa, Fig. 12 Abidjan, Côte d'Ivoire. Courtyards are used for domestic activities and sometimes for economic activities. Here, women sort candies they are going to sell in the street and at the markets. On the right front, notice the collective place dedicated to the dishes and the washing. Barrels (*red* and *blue*, on the left rear) indicate that there is no tap water in the compound. Women are in charge of getting the water (© IRD – Philippe Haeringer)

unauthorised neighbourhoods thus have access, to some extent, to the highest-priority services. The situation is nevertheless not very satisfactory. Poor sanitation is a major health issue, water that is expensive and remote encourages drinking of non-potable water, and unregulated transport is dangerous. Furthermore, the privatisation of urban services, in line with structural adjustment recommendations, has worsened the situation since the mid-1980s (Stren & White, 1989).

In a nutshell, West African cities and towns face the same problems as other developing regions in terms of access to services and housing. However, due to the informal land tenure and housing systems, squatting (A distinction must be made between squatting (deliberately building on land without permission and against the owner's wishes) and unauthorised settlement (building in areas where the government has not given permission to build, but where customary owners can sell plots for construction)) and slums are much less extensive than in Asia and Latin America (Konadu-Agyemang, 1991; Peil, 1976). A regional study found that 'only' (sic) 15–25 % of urban residents lived in precarious housing (shanty towns), a similar proportion in planned districts, and the remainder, i.e. the majority, in structured, albeit informal, neighbourhoods. However, the fact remains that in the poorest neighbourhoods, living conditions are so bad that infant and child mortality rates are sometimes higher than in rural areas (United Nations human settlements programme, 2003; National Research Council, 2003).

Urbanisation is known to be historically associated with development. In the past, when the developed world experienced its transition from a predominantly rural-agricultural economy to an urban-industrialized one, urban growth was the highest where economic growth was fast. The urbanisation process in sub-Saharan Africa differs to some extent from the process experienced by contemporary developed nations at a comparable stage in their development (Njoh, 2003). There is nevertheless a consensus nowadays to recognize that the level of urbanisation (percent urban population) is correlated to various development indicators, such as the GDP per capita or the Human Development Index (Davis & Henderson, 2003; Njoh, 2003). Therefore recent slowdown trends of urban growth, especially where migratory reversal occurred, may be worrying in terms of development. Actually, these

Cities and Towns in West Africa, Fig. 13 San Pedro, Côte d'Ivoire. A woman buys water from a neighbour who is equipped with running water. The scene takes place in the Bardo, the largest informal settlement in Côte d'Ivoire; 90,000 people (about to thirds of the town population) lived there in 1998. San Pedro is the perfect example of the urban planning failure in West Africa. It is a new town, created in 1968 to be the exportation (cocoa, wood, etc.) port of the southwest of Côte d'Ivoire. From the beginning, the Bardo, the unplanned part of the city, started to grow faster than the authorized part (© IRD – Philippe Haeringer)

trends reveal a polymorphous crisis, i.e. both a crisis of urban management (unsolved problems of housing, services, infrastructure, etc.) and a crisis of the urban economy (increasing unemployment, insufficient income, high cost of living, etc.). From a global point of view, the peripheral position of the West African countries in the world economy appears to be the main reason for their lagging urbanisation (Simon, 1997). West African countries are still excluded from the more profitable production sectors. Their economies are still highly dependent on raw materials and from this end they are not able to control the world markets. In this context, West African states remain highly dependant upon international aid. As a consequence, conditions imposed by the financial institutions weigh heavily on national economic and urban policies. Urban management issues are thus more and more delegated to (new) municipalities, which dispose of fewer means. Public services are often privatized, but the poorest do not have necessarily better access to them. Drastic reductions in public expenditure prevent states to invest in infrastructure (electricity, roads, etc.) that are recognized to be necessary for the population's wellbeing and for the enterprises' prosperity. West African states have to reconcile on one hand the conditions that will allow private informal and formal enterprise to expand in towns and cities in order to generate wealth and employment and on the other hand extend basic services in order to guarantee a better health and education for the poor.

Extra 1 Inconsistent Definitions and Measures Vagaries

What is rural? What is urban? There is no global standard to define the line between urban and rural settlements. This issue is not specific to West Africa, but it is particularly relevant there because of frequent discrepancies. For instance, in Côte d'ivoire, the official definition published in 1975, based on population and activity criteria, has never been used in practice (a list of cities has been established without regard for the official definition) (Dureau, 1987). Furthermore, there are often inconsistencies between national official definitions and definitions published in UN reports (practically the only comprehensive source of international urban data available). In the UN's Statistical Yearbooks, definitions are not stated for some countries, even though this information is available in national reports (e.g., Benin, Burkina Faso and Guinea). Definitions for other countries (e.g., Côte d'ivoire, Mauritania and Niger) are even in contradiction with national definitions. Obtaining information on the

Cities and Towns in West Africa, Fig. 14 Mopti, Mali. A water street vendor (© IRD – Sophie Martin)

Cities and Towns in West Africa, Fig. 15 Dakar, Senegal. The official public transport system is not sufficient to serve the whole agglomeration and is too expensive for a large part of the population. Private mini-buses, the so-called 'cars rapides' in Dakar (it means fast buses), compensate for this inadequacy. But since the material is old, they are not always secure and contribute a lot to pollution (© IRD – Michel Dukhan)

definition of urban settlements in West Africa is in itself a challenge. In any case, one observation can be made: the definition of 'urban area' varies from one country to another, and can also vary over time, which makes geographical and chronological comparisons problematic. As a result, most publications on urban trends based on UN data are flawed by the inconsistency of definitions (Bocquier, 2003).

In order to draw a more accurate figure of urban trends in the world, Moriconi-Ebrard (1994) has created an urban database based on a standardised definition: in GEOPOLIS, settlements with a population over 10,000 are considered urban, regardless of country and period (from 1950 to now). This new definition could have a major impact on national figures. However, in the case of West Africa, using a standardized definition does not produce a very different figure of urban trends on the regional scale. The level of urbanisation measured by official definitions appears to have been slightly overestimated, but trends remain similar. The pace of urbanisation in West Africa slowed sharply in the 1980s and 1990s.

Urban studies in West Africa are not only flawed by definition problems. They are seriously hampered by a lack of reliable and up-to-date demographic data. Census data are the principal sources of information on urbanisation. But

censuses tend to be conducted only once a decade and then take several years to be analysed and published. In Africa, deadlines are often delayed due to financial, political or security reasons, so that recent data are rarely available. As a result, figures shown in UN publications are often estimates. Because of the poor quality of available data and an inappropriate projection method (Bocquier, 2005), estimates for West African countries in the 1980s and 1990s have overrated urbanisation levels. To conclude, statistics on urban trends should be used with caution!

Extra 2 The Urban Future: Mega-Cities or Small Towns?

Contrary to popular perception, most urban dwellers in Africa do not live in the slums of mega-cities. In fact, most African cities are small by international standards. Lagos in Nigeria is the only sub-Saharan African urban agglomeration to be included in the UN list of the 30 largest urban agglomerations in the world. Urban systems in Africa, and more specifically in West Africa, are quite different from those in Latin America or Asia. There are no major metropolises (with the exception of Lagos), but many small and medium-sized towns (as a result of the reclassification process). It is precisely because large cities play a less clear-cut role in urban dynamics than in other parts of the developing world that this is such a controversial topic among academics.

Some authors stress and decry the high degree of primacy, where a large proportion of the urban population lives in a single city. This view is widely shared by policymakers who are concerned by the growth of large cities and who claim to have developed policies to reduce migration to cities (United Nations, 1998). Some African cities do clearly predominate in national urban systems (e.g. three-quarters of the urban population of Guinea were living in Conakry in 1994, according to UN data) and have seen spectacular growth, especially in the 1970s (e.g. Abidjan grew by more than 10.3 % per year between 1965 and 1975, a record rate of urban growth). Furthermore, several studies have shown an increasing concentration of the urban population in the main cities in recent decades; urban systems seem to have evolved from undersized to oversized capital cities as compared to the world average (Bocquier & Traoré, 2000).

Conversely, some authors argue that urban growth in West Africa is largely due to the development of small and intermediate towns. Using other data sources or other calculation methods, they show that primacy is no greater than in other regions of the world and that it has not increased over time (Bocquier, 2003; Cour & Snrech, 1998). Indeed, in most countries, the principal city's share of the total urban population has not changed much since the 1950s. For instance, Dureau (1987) has shown that Abidjan has concentrated about 40 % of the urban population of Côte d'Ivoire since 1936 and that, even when the city saw spectacular growth (1965–1975), 49 % of new urban dwellers settled in secondary towns. In fact, in the mid-1980s, West African small and medium-sized towns became a separate subject of research (Baker, 1990; Dubresson, 1996; Hardoy & Satterthwaite, 1986). Several studies stressed the importance of their development. In West African countries, the number of small towns (settlements with a population of 5,000–20,000) rose from 150 in 1960 to 400 in 1980 (Giraut & MoriconiEbrard, 1991) (see Map 1).

What is the urban future? Projections are always hypothetical, especially when they are related to such controversial issues (Bocquier, 2005). Nevertheless, a consensus is emerging. Despite popular perceptions to the contrary, West African people will not all be living in mega-cities in the near future. Primacy may increase in some countries, but it may result from regional integration. Cities like Dakar, Abidjan and Lagos are highly cosmopolitan and their share in the urban population would be more accurately assessed at the regional level (West Africa) than at the national level. In any case, small and medium-sized towns will continue to appear (through reclassification) and grow.

Extra 3 Migration, Urbanisation and Development: A Controversial Issue

Does rural-to-urban migration (and the resulting urbanisation) favour economic development? This question, which is a matter of policy concern in West Africa is also vigorously debated by scholars. Broadly speaking, there are two main contrasting viewpoints.

An anti-migration viewpoint is that rural-to-urban migration is excessive and should be curbed because it leads to a "less than optimal allocation of labour between the rural and the urban sectors" (Gugler, 1982). On the one hand, it exacerbates unemployment and underemployment in African cities. On the other hand, it reduces potential agricultural output, by depriving the rural population of its more innovative and able-bodied members. Furthermore, rural-to-urban migration is criticised as the primary contributor to the uncontrolled expansion of urban areas (Bairoch, 1985). Finally, rural-to-urban migration increases the cost of providing for the country's population in two ways. Firstly, new infrastructure is required by the migrants, and amenities (housing, transport, garbage and sewage disposal, etc.) are more expensive in cities or towns than in rural areas, where they may not be needed at all (Gugler, 1982). Secondly, urban job creation is generally more costly than rural job creation, because most jobs in the industrial sector require substantial complementary resource inputs. For these reasons, rural-to-urban migration is seen "both as a symptom of and a contributor to African underdevelopment" (Todaro, 1997). This view is largely shared by policymakers (United Nations, 1998).

Taking the opposite point of view, pro-migration authors argue that it is completely inappropriate to regard migration as an undesirable force, which needs to be suppressed (Amis, 1989). On the urban side, authors acknowledge that substantial unemployment and severe underemployment characterise most large African cities today, but they point out that, on average, migrants must be better off in urban places, otherwise rural out-migration flows would slow (Becker, Hamer, & Morrison, 1994). On the rural side, they argue that there is no labour shortage since emigration has not prevented the rural population from increasing far more rapidly than it has ever increased in the developed countries (except in the United States). On the contrary, rural out-migration is seen as a way of alleviating human pressure on natural resources. In addition, they contend that urbanisation stimulates agricultural activities, since it creates a market for specialised food production with high added value (market gardening and poultry farming). Apart from the impact on rural areas, migration and urbanisation are seen as key components of the development process. Authors argue that, for several reasons, increased urbanisation raises per capita income and other measures of economic welfare. First, when driven by rural-to-urban migration, urbanisation tends to move workers from agriculture to more productive occupations (e.g. urban services, commerce, and manufacturing sectors). Second, urbanisation offers the cost-reducing advantages of economies of agglomeration and economies of scale and proximity as well as numerous economic and social externalities (e.g. skilled workers, cheap transport, amenities, etc.). Finally, urbanisation also contributes to development in more subtle ways. For example, it may lead to lower levels of fertility and mortality, as individuals benefit from improved access to health care. Theory apart, Becker et al. (1994) stress that, from a macroeconomic point of view, while less than a third of Africa's population lives in cities or towns, these centres generate over half of the continent's gross domestic product (GDP).

To conclude, one is tempted to agree with Portès, who takes the view that "internal migration and urban growth are intrinsically neither good nor bad. Such assessments depend upon the specific social context, and in particular, on the point of view one adopts with respect to the different classes and institutional actors. A case can be made that, in the short run at least, the present trends of rural-urban migration and urban concentration are functional for a wide assortment of groups" (Portès, 1985).

See Also

- ► Architecture in Africa, with Special Reference to Indigenous Akan Building Construction
- ► Building Construction in Africa: Akan

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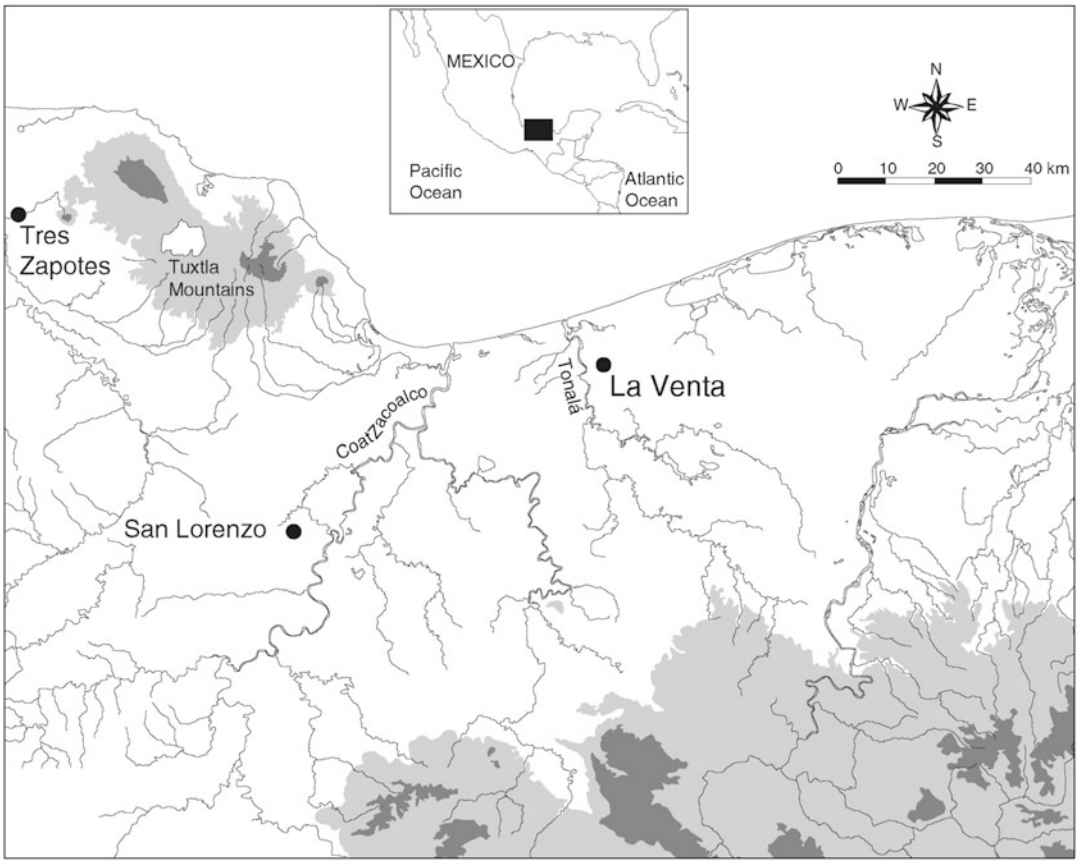
Cities and Towns of the Olmec

John E. Clark

Mesoamerica's first civilization arose about 3,400 years ago among the Olmecs of the tropical Gulf Coast lowlands of southern Mexico (Fig. 1).

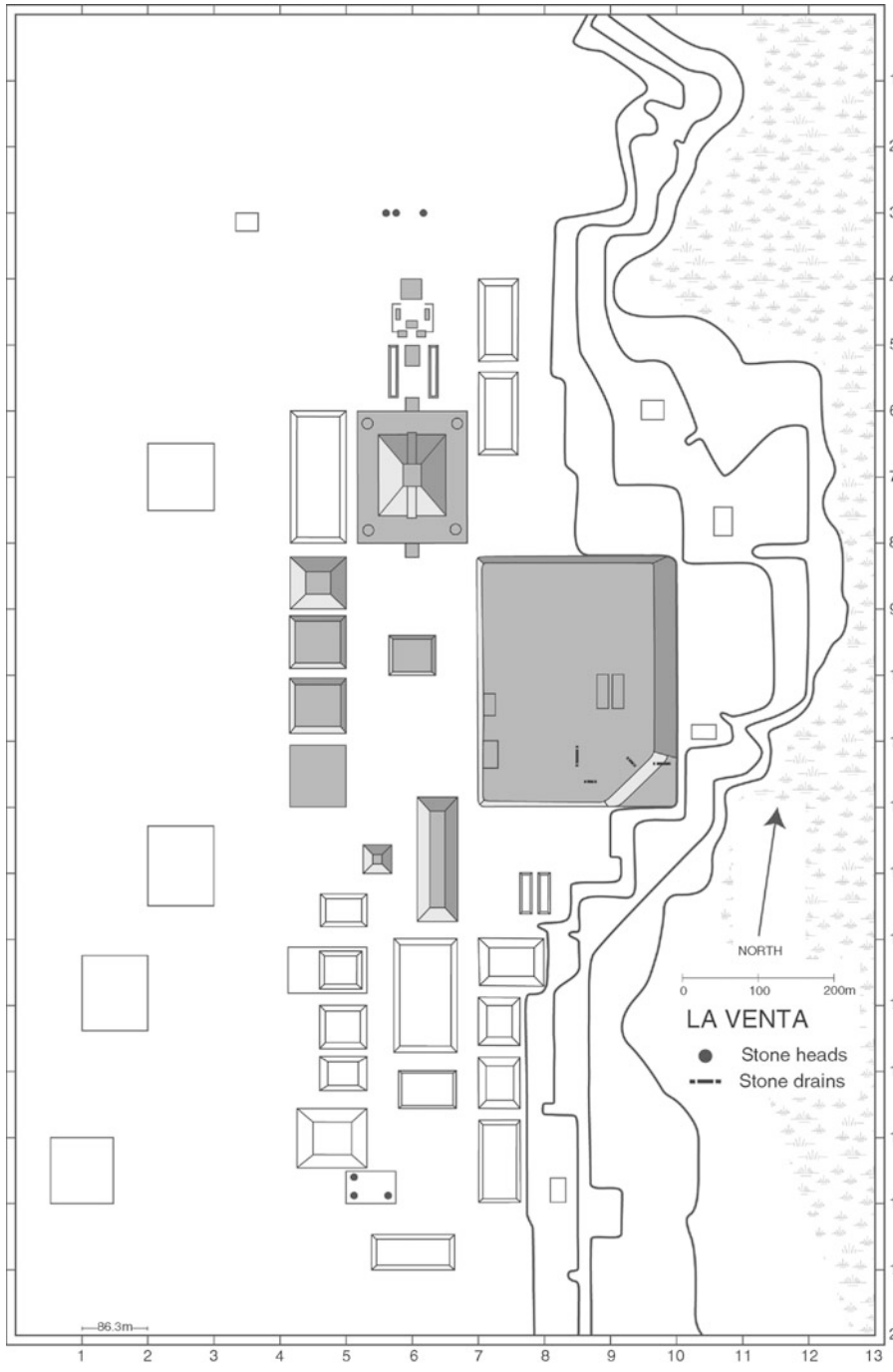


Cities and Towns of the Olmec, Fig. 1 Map of Mesoamerica showing the Olmec region and its principal sites

Olmec civilization lasted a 1,000 years and is recognized by its spectacular and unique art style manifested in colossal stone heads and thrones, figurines, carved pottery, and polished and incised jade objects. Among their many accomplishments, Olmecs created the first cities in North America. Many archeological sites are known for this culture, but only two were large and splendid enough to qualify as cities: San Lorenzo and La Venta. As capitals of dynastic societies and habitats of kings, some bureaucratic functions and services were unique to these cities, as evident in their palaces, thrones, royal tombs, ballcourts, temples, observatories, and state art. Scholars expect cities to accommodate 5,000 or more people. By the standards of function and size, San Lorenzo was Mesoamerica's first city. It enjoyed a meteoric but brief history and was succeeded in the same region by La Venta, the last Olmec city. For its part, La Venta represented the first mature manifestation of the quintessential Mesoamerican city, and it was a model of a sacred center copied by other peoples. Key issues in Olmec studies are the historic and formal relationships between San Lorenzo and La Venta. These are most easily appreciated by beginning with La Venta and tracing some of its features back to San Lorenzo.

The Last City, La Venta

La Venta was founded and built about 850 BCE on virgin soil in a special place: a long, 20 m high island in the middle of a vast swamp in western Tabasco, Mexico, just 15 km from the coast. La Venta was abandoned about 400 BCE and never reoccupied. This was a fortunate happenstance for investigators because the city has been



Cities and Towns of the Olmec, Fig. 2 Map of La Venta, Tabasco, Mexico. The *gray* areas indicate the early part of the city

preserved as the Olmecs left it 2,400 years ago. The map of the site in Fig. 2 indicates the probable early and final form of this city. At its founding, La Venta was laid out along the eastern edge of the island. This escarpment was cut and terraced to bring it into alignment with the principal axis of the-shaped city. Some of the construction fill used to build the city may have come from these land modification operations.

La Venta was built to a rigid plan, in regular 86.6 m blocks, and along a centerline oriented 8° west of north. The original city center was 10 blocks long and 8 wide. Subsequent additions to the city respected the principal axis and measurement interval. Later mounds encroached on the original mounds in the north. The monumental city center eventually extended 1,482 m, or 17 blocks. Late in its history, stone monuments were set up as boundary markers. Three basalt colossal stone heads were placed at the northern end of the city, and they faced north. Three even larger sandstone heads near the southern end faced south. These monuments were placed 1,300 m or 15 blocks apart.

These building intervals, when translated into native Mesoamerican beliefs and practices, show that La Venta was built as a sacred center. The Olmecs measured this city with the 1.67 m fathom used by the later Aztecs and Maya; thus, the 86.6 m block represented 52 fathoms, the year count for the calendar round. Five such macrounits comprise the number of days in the sacred almanac (260), and seven (364) approximate the solar year. These calendar distances separate critical points in the arrangement of buildings at La Venta. For example, the original city was ten blocks long, or 2×260. Later additions to the site extended it seven blocks, or a solar year count. Other ritual counts are built into the placement of mounds and monuments. They demonstrate that La Venta was carefully planned and built with marvelous precision.

The city was partitioned and arranged according to function. The original layout shows a long, 6 ha plaza (2×4 blocks) with special architecture in each cardinal direction. The plaza was probably for public ceremonies and for viewing rituals performed on the platforms surrounding it. The plaza could have accommodated well over 100,000 standing spectators. Looking north, a spectator would see a 32 m high stepped pyramid made of nearly 100,000 m^3 of dirt and clay. A temple of perishable materials probably graced the top of this artificial mountain. The summit could be accessed from stairs on the south and north faces. The pyramid is the only promontory for over 100 km on this coastal plain and can be seen from over 10 km away. It would have been very impressive close-up in its final form. The pyramid was given a new clay skin several times during the city's history, each time making it slightly bigger and taller. The height of the original pyramid has not been determined.

East of the plaza lies a broad 8 ha platform or acropolis that required nearly twice as much earth and clay to build as the pyramid. This high platform was probably the royal compound: residence of the king, his courtiers, and servants. A ballcourt and an elaborate system of subterranean stone drains have been identified there. In the block south of the plaza lies a long mound flanked on the west by a short pyramid. Together these constituted an astronomical observatory for monitoring the movements of the rising sun through the year, perhaps to coordinate the agricultural cycle and other state rituals. Looking to the west a spectator would see a string of low platforms and their perishable buildings, probably priests' residences or special temples. Axial symmetry is evident in the organization of the original city. Buildings on facing blocks around the plaza were complementary pairs: the pyramid and observatory formed a N-S pair, and the royal compound and priestly residences an E-W pair.

North of the pyramid block a compound was built one fourth the scale of the rest of the original city. The main complex consisted of five low mounds surrounded by a 2 m high and rectangular palisade of upright, basalt pillars. Spectacular jade and serpentine offerings and royal tombs were found in this sector arrayed along the principal axis, and on both sides of it. Some individual offerings had more than 1,000 tons of serpentine. A pair of offerings depict the abstract face of the earth lord, each on top of 28 layers of

carefully placed serpentine rubble. The two images look identical but are color coded to depict an ►east and west image of the same entity. All rock used in these offerings was imported from over 60 km away, so the massive offerings represented a tremendous burial of wealth. Another expense was the importation of tons of basalt for stone monuments and architectural enhancements. These were brought in by canoe or raft from over 100 km of inland waterways. To date, 90 stone monuments and hundreds of 1-ton basalt pillars have been discovered in the city. Sculptures include colossal stone heads, thrones, full-figure images of kings, and low-relief carvings on flat slabs, or stelae. The latter depict gods or narrative scenes. The south side of the great pyramid had a line of six stelae facing the main plaza, three on each side of the stairs.

The mounds added to the southern end of the city later in its history are not as logically arranged as those of the original city. Presumably, they were for privileged personnel and state functionaries. With the exception of the six monuments used as boundary markers, large stone sculptures were confined to the northern part of the city, the domain of La Venta's lords and priests. The oldest buildings in the north were rebuilt or refurbished many times during their centuries of use.

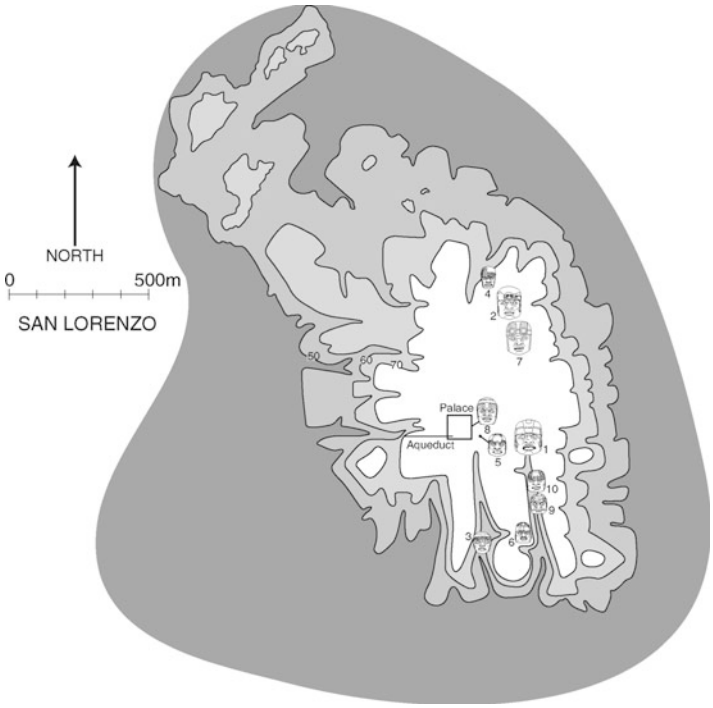
In its final form the city center was about 58 ha in extent, and with its residential neighborhoods the whole city covered at least 200 ha. At its height, the city housed 3,000–5,000 people, with many more on small islands and river levees within 10 km of the city. The extent of the La Venta kingdom has not been determined, but the city was the royal capital for towns and villages located over 100 km distant. La Venta kings were depicted as corn gods, indicating that the city was governed by divine kings, or priest-kings. The institution of kingship became fundamental to Mesoamerica statecraft; its beginnings can be traced to San Lorenzo.

The First City, San Lorenzo

San Lorenzo was occupied off and on from 1750 BCE to AD 1100, but it only functioned as a city from 1300 to 1000 BCE, at which time it reached its maximum extent of 500 ha, over twice the size of La Venta in its prime. San Lorenzo collapsed about 1000 BCE, perhaps due to a shift in the course of the Coatzacoalcos River. The city is located 60 km from the coast and currently lies 7 km west of the meandering Coatzacoalcos, the second largest river in Mexico. Just over 3,000 years ago, this river ran on both sides of San Lorenzo, making the site an island and well positioned to control canoe traffic and commerce. The city core lay atop the summit of a 50 m high natural plateau nearly 60 ha in extent. The surface of the plateau was carved and stretched into a ⊥-shape, with the N-S crossbar being nearly twice as long (1,213 m) as the E-W axis (650 m). Elite houses, public buildings, and special stone statuary were confined to the top of the plateau, with residential terraces encircling the heights and spilling down and across the plain below. San Lorenzo was the capital of a region that extended 40 km up and down river. At least 7,000–10,000 people lived in the city in its heyday, with four times as many in subordinate communities and provinces.

Little is known of the layout of San Lorenzo because the city lies a meter or two beneath the current surface, so its format will only be revealed through excavation. The few mounds on the plateau postdate the Olmec occupation. A striking difference with La Venta is that early San Lorenzo lacked pyramids. Recent research discovered a palace with an inner courtyard; a colossal stone head and throne were on display there, demonstrating that stone monuments were associated with royal architecture and that some were buried in place. Plazas and temples have not yet been identified. Ballcourts are known at a junior center and may eventually be found at San Lorenzo.

Judging from the size and shape of the modified plateau top, and the first level of broad terraces below the summit, San Lorenzo was arranged in the same measurement increments as La Venta. The original cruciform of the plateau was 14 × 9 blocks. Another five blocks are evident in the descending terraces on the western and eastern extensions, making the planned city center a 14 block square, or 2 solar years on a side.



Cities and Towns of the Olmec, Fig. 3 Map of San Lorenzo, Veracruz, Mexico, showing the distribution of colossal heads, the E Group palace, and long stone aqueduct. The heads are shown to scale relative to each other

The shape of the plateau and alignments of stone heads and aqueducts demonstrate that the central part of San Lorenzo was rectangular and aligned to N-S and E-W axes, with the long axis 1° west of true north (Fig. 3). Both cardinal axes at San Lorenzo were important, but the axial symmetry of the city unfolds from the E-W centerline. When Olmecs built La Venta, they rotated the basic San Lorenzo plan 90° counterclockwise so the most important cardinal direction became north instead of east. San Lorenzo was formally organized and zoned from the center of the plateau outward, and downslope. Residential status decreased as a function of distance from the center. The only palace identified so far was built near the western edge of the city's center (Fig. 3), opposite its placement at La Venta. The San Lorenzo palace was placed near a freshwater spring, and a 171 m long aqueduct ran west from its courtyard to the edge of the plateau. If the colossal stone heads were buried in palace courtyards, their distribution suggests that each king had his own palace and that these shifted during San Lorenzo's history from the west edge of the plateau to the east.

As at La Venta, much engineering and earth moving went into constructing San Lorenzo. The first task in building the city was to level the plateau and extend and straighten some of its edges. The eastern and southern faces appear to have been the most precisely cut, and even after nearly 3,000 years of erosion, their straight, perpendicular edges can be appreciated (Fig. 3). Ramps and causeways were created for hauling the colossal sculptures to the summit. A complex system of stone drains was also installed at their proper gradient.

Many specialized artists, artisans, and bureaucrats resided at San Lorenzo, and they were supported by food brought in from outlying settlements. The clearest evidence of subsidized citizens shows up in the site's 130 stone monuments imported from 60 km away, some of them weighing over 20 tons. The best known are thrones and colossal heads. The latter are thought to be realistic portraits of individual kings. Judging from similarities of facial features, at least three families appear represented in the San Lorenzo king list. These kings were depicted as warriors and heroes rather than gods, as

became the subsequent practice at La Venta. Together, the San Lorenzo heads displayed the city's royal dynasty – the first in Mesoamerica. The artistry and labor evident in these monuments, and the organizational requirements for carving and dragging them through the jungle to the city, reveal the presence of other citizens: artisans, overseers, haulers, and probably slaves.

In summary, similarities between San Lorenzo and La Venta include their orientation, cruciform shapes, concentric zoning, size of city centers, standard block sizes, spacing by calendar distances, axial symmetry and complementarity, palaces, and abundant monuments of gods and kings. Significant differences are the presence of pyramids and special monumental architecture at La Venta and the emphasis on north as the sacred sector of the city, the place of the tallest pyramid. The small hamlet at San Lorenzo at 1750 BCE evolved in place into a glorious city in just four centuries. In contrast, La Venta was planned as a special city before the island was occupied. Many later Mesoamerican cities mimicked the formal layout of La Venta rather than that of San Lorenzo. The latter's contribution was getting kingship and city building started, not giving them their final form.

See Also

► Pyramids of Mesoamerica

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City and Town Planning of the Maya

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Like cities and towns in many societies, those of the ancient Maya express a spatial logic that mapped the cosmos on the landscape. The Maya cosmos has three vertical layers, ordered by four world directions and a center. Within this structured universe, the Maya – today and in antiquity – have established towns and cities whose properly ordered space makes possible the pursuit of properly ordered lives. The towns and cities of the ancient Maya materialize these ideas, and in the variable forms of their physical expression, modern observers can discern the intertwining of primordial beliefs with historically specific political strategies. Such discernment depends on understanding the structure of the Maya world, the importance of the heavens, the role of political dynamics, and the importance of people's earthly movements and ritual practices in bringing the planned order to life. The whole is examined below in the plans and practices for multiple, well-known ancient Maya cities and towns.

Establishing a Place in an Orderly World

Above and below the world of daily life are supernatural realms, to which physical connections exist as caves and other openings in the earth, as well as in the mountain peaks stretching skyward (Brady, 1997; Stone, 1992). Each Maya community recognizes a sacred mountain, with one or more caves, that ground the village, town, or city in the world and to which community members make regular pilgrimage (Patel, 2009). Along with caves, rivers, seas, and all other bodies of water are conduits to an underworld described as a watery place, as non-Maya observers can witness as well, in the subterranean waters of the limestone karst landscape comprising much of the Yucatan peninsula. Roots of

earthbound trees reach into that underworld as well, while their trunks ascend toward the heavens. The towering *ceiba* tree, in particular, is designated in Maya imagery as the World Tree, the center of the universe, and the *axis mundi* around which the rest of the world is disposed. For this reason, many modern Maya towns in Guatemala have a ceiba in the central plaza.

Together with the center, the four corners of the world define a five-pointed quincunx pattern, whose physical manifestation expresses order and completion. Whenever any new place is established – from milpas (cornfields), to domestic altars, houses, towns, and cities – the four corners and the center must be designated and ritually consecrated (Ashmore, 2005; Freidel, Schele, & Parker, 1993; Johnston & Gonlin, 1998; Mathews & Garber, 2004; Tedlock & Tedlock, 1985; Vogt, 1976). As elsewhere in Mesoamerica, each of the five points involved has its own characteristic color, tree, bird, animal, and deity (Bassie-Sweet, 1996). Not surprisingly, east is the position of the red rising sun, while black of the west is linked to the setting sun. North is white, south is yellow, and center is green – the color of corn plants, jade, and all things precious and new. Offerings in dedication of new construction frequently partake of this symbolism to situate the locale properly in the world. These microcosmic offerings might take the form of a cache of appropriately colored pebbles at a farmer's house (Robin, 2013, pp. 76–78), while for a civic building the microcosm might comprise a deposit whose layered shell, jade, and bird bones betokened sea, earth, and sky (Sharer, Fash, Sedat, Traxler, & Williamson, 1999, pp. 237–238), or positioning ritual offerings at the four corners and center of a building meant to mark a city's *axis mundi* (Bell, 2007, p. 341).

Maya space is also ordered by time, and from time immemorial, the calendar ordained perpetual succession of the four cardinal world quadrants, or more specifically their associated deities, in their responsibility for overseeing events of a 365-day period (Coe, 1965). As elsewhere in Mesoamerica, the calendar reckoned time simultaneously according to a 260-day "sacred year" and a 365-day "vague" solar year. The latter comprised 18 months of 20 days each, plus an unlucky period of 5 days, called *Uayeb*, at the transition to the next year. Mathematically, a year in the 365-day cycle could begin on only one of four named days in the 260-day cycle. In sixteenth-century Yucatan, these 4 days, called "year bearers," were *Muluc*, *Ix*, *Cauac*, and *Kan*, and each was associated with one of the cardinal directions. Dances, blood sacrifices, and feasts at the end of each year, known as Uayeb rites, formally marked transfer of responsibility from 1 year bearer to the next, passing in a counterclockwise direction (Muluc, east; Ix, north; Cauac, west; Kan, south). Because images of the deities of those year bearers were housed in the civic center during the year, the places involved and ritual passage between them encompassed the city or town in a quincunx pattern.

These are the basic components and activities from which town and city plans are generated and brought to life, but they are shaped by other considerations, as well, including astronomy, the world's creation, and worldly politics.

Astronomy and Creation

Scholars have long acknowledged the astronomical sophistication of the ancient Maya. Buildings are often demonstrably oriented to the rise or set point of particular celestial bodies, especially Venus and the Pleiades, or arguably to chart wider-scale changes in the sky with the seasons. The Caracol at Chichen Itza, Mexico, is especially well known as an observatory (Aveni, 2001). Ancient builders also choreographed hierophanies – manifestations of the sacred (Eliade, 1959) – by positioning windows, doorways, stairs, or other architectural elements to shape light or shadow at key times. Examples include the serpent shadow that appears at equinox sunset on the north stair of the Castillo, Chichen Itza. At Yaxchilan, the rising sun on the summer solstice shines through the doorway of a building situated deliberately to catch that light, to illuminate a statue of Bird Jaguar III,

a king of the city in the seventh century AD (Tate, 1985). At Palenque, the setting sun at winter solstice appears to dive into the tomb of seventh-century king Pacal the Great, in the Temple of the Inscriptions, while the last rays of light shine on an image of God L, a lord of the underworld into which the sun – and its earthly incarnation, Pacal – has descended (Schele, 1977). A small compound in Belize, aptly dubbed Quincunx for its layout, indicates that rural farmers, too, used architectural assemblages to monitor the sun and the seasons (Zaro & Lohse, 2005).

In the early 1990s, prominent scholars began to write of the sky as a map of Maya creation (Freidel et al., 1993). That is, they linked the acknowledged astronomical sophistication to its citation in ancient times and interpreted many instances of texts and imagery as relating primeval events set forth in the *Popol Vuh*. The latter is an eighteenth-century document committing to paper the oral accounts of creation, according to the Quiche Maya of highland Guatemala (Christenson, 2003; Tedlock, 1985). In it, sequential acts by named creator beings establish the universe as people know it. The objects and actors involved in the narrative enact its key episodes eternally in the night sky. The sun, moon, and Venus are exceptionally potent actors in shaping the Maya universe. But because the observed positions of astral bodies change with the hours and the seasons, the roles of particular stars and planets likewise shift in the course of the celestial narrative. For example, in the early predawn hours of February 5, the Milky Way appears to tilt erect, and according to this interpretation, the apparent movement is read as the raising of the World Tree and, with it, the primordial raising up of the sky. The same action separated the earth from the sky and divided the world into quarters (Freidel et al., 1993). Since that time, each properly established town and city has had its own World Tree, embodying its original counterpart at the center of the four quarters of the world (Coggins, 1982; Freidel et al., 1993). The materialization of an *axis mundi*, often as a tree, is well known in other Native American societies and in other parts of the world (Eliade, 1959; Tuan, 1977).

Political Ideology

If the foregoing had exhausted the factors in Maya city and town planning, all resulting plans would have been very similar, if not exactly the same. The observable variation in plan, however, can be understood as reflecting, as well, the competition, strategies, and assertions of Maya political history. Most fundamentally, the kings who ruled Maya cities sought not only to map the cosmos and situate their city at the center of the universe, but they also aimed to place themselves in cosmically sanctioned positions of authority, in order to personify creator deities – especially the sun – and re-enact the central events of creation.

Most commonly, this political positioning involved placement of palaces, tombs, shrines, and royal arenas in cardinal locations of strength. Perhaps the clearest material expression of such mapping is a series of complexes at Tikal, known as twin-pyramid groups. Flat-topped pyramids flank east and west edges of a spacious open platform that could accommodate gatherings of hundreds of the king's subjects. To the south is a low building with nine doorways into its single room. On the north edge of the platform is an unroofed enclosure containing a single pair of sculptures, the upright one of which displays a portrait of the king who commissioned the construction. Clemency Coggins (1980) describes this as a map of the cosmos, of the vertical path of the sun turned 90° on its side to accommodate the practicalities of construction. The two pyramids mark the sun's rise and set points, and the southern building houses the Nine Lords of the watery underworld. That position is at the nadir of the sun's path, and thus, metaphorically, "down." To complete the solar circuit, the northern building would represent "up" and would thereby place the ruler, through his portrait, in the sky, together with his ancestors and other powerful supernatural beings – especially his avatar, the sun, at its most powerful midday position overhead.

Tikal's twin-pyramid groups offer a key to understanding the significance of the pervasive north–south axis in Classic period civic centers (Ashmore, 1989; Ashmore & Sabloff, 2002).

Preclassic towns and cities, such as Nakbe or El Mirador (ca. 600 BCE–AD 250), tended to emphasize an east–west dimension and thus seem to focus on the rise and set points in the sun's transit. The shift to a prevailing north–south axis in the Maya lowlands might reflect emulation of the great city of Teotihuacan, in central Mexico, and its Street of the Dead, or even the increasingly well-documented direct intervention of Teotihuacan lords and their emissaries by the late fourth century AD (Cowgill, 2000; Stuart, 2000). The significance of the north–south axis is arguably related to celebration of the Maya king as personification of the raised-up World Tree at the moment of cosmic creation (Ashmore, 2005; Schele & Freidel, 1990).

Then as now, to establish a place properly required dedication rituals. Individual buildings were "ensouled," given life, and ultimately terminated, all by action of the city's leader and his people (Gillespie, 2000). Indeed, Marcus, (1983) remind us that in the view of native peoples of Mesoamerica, the affiliation of people with king – or other community leader – was more important than place or territory in social identity. One "belonged to a particular region controlled by a specific native ruler, to whom he owed allegiance and tribute and from whom he received protection and civic-ceremonial leadership" (Marcus, 1983, p. 208). In that vein, planning a city, or reshaping its plan, likely involved public processions, along with sacrificial rites variably open to public view (Fash, 1988; Maca, 2006; Reese-Taylor, 2002), as evident from town city and town founding elsewhere in the world (Rykwert, 1988).

These political considerations shape the earlier statement that Classic-period views on the structure of the Maya cosmos were pervasive, across scale of material expression and social standing of those making the expressions. It therefore should not be surprising that planning is most obvious in the core of towns and settlements (Marcus, 1983). In the sixteenth century, Bishop Diego de Landa, the second Bishop of Yucatan, described Maya towns as concentric rings of settlement, with the leaders and the most important civic spaces at the center and people and activities of progressively lower civic standing ever more distant from that center (Tozzer, 1941, pp. 62–64). Furthermore, according to Landa, "every town in Yucatan [also] had two heaps of stone 'facing each other' at each of four entrances to the town [which were] placed according to the four cardinal directions" (Coe, 1965, p. 100).

Analyzing Observable City and Town Plans

The foregoing principles were expressed in varied specific arrangements and at different scales. Reasons for such variation probably reflected, at least in part, strategies of the person or group in charge of the planning, and in the case of an ancient Maya city, that would have been the king. Changes in dynastic fortune, conquest, and usurpation would have allowed new rulers to rewrite not only textual history but also city plans (Jones, 1991; Sharer et al., 1999; Traxler, 2004). Classic Maya texts indicate that political alliances, warfare, and intrigue among royal houses altered individual polity fortunes repeatedly, although two "superstates," Tikal and Calakmul, seem to have been enduring foci of lowland alliance networks (Martin & Grube, 2000).

At Tikal, for example, the aforementioned twin-pyramid groups reflect plans of dynastic heads in Late Classic times there, in at least the seventh through ninth centuries AD. Similar invocation and weighting of cardinal directions seems evident in the layout of the Great Plaza area of that city around AD 700, under the same ruling house. In that instance, the pyramids were mortuary shrines, and the bodies of royal ancestors literally lay buried in what mapping teams dubbed the North Acropolis – recognized now as truly a necropolis on the north. But civic constructions of that time had followed major political upheavals and separated the planners from antecedents of the Early Classic (ca. AD 250–600). In that earlier age, emphases on an east–west solar axis are evident in the principal orientation of buildings, where a solstice

observatory complex dominates the civic core (Laporte & Fialko, 1995).

The complex in question manifests a form established elsewhere by the Middle and Late Preclassic (ca. 850 BCE–AD 150), and its early expression is astronomically accurate in such locations as Group E at Uaxactun. Subsequent proliferation of so-called E-Groups across much of the Maya lowlands, however, "served as an architecturally standardized focal assemblage for integrating Late Preclassic and subsequently Early Classic Maya populations, first ritually and then dynastically" (Chase & Chase, 1995, pp. 100–101), and constituted citation and commemoration of the architectural form, more than functioning observatories (Aimers & Rice, 2006; Fialko, 1988). That is, as emphasis on the person of the king expanded, earlier foci of celebration received less attention, in architecture as in other material forms of expression. The picture of ideological transformation that emerges underscores the role of political affiliations, continuities, and disjunctions in shaping construction programs and the city planning of which those were part. The impact for observers today is that the shallower the history of a city is, and the more stable its ruling house, the more likely are we to discern intended civic plans from the cumulative constructions (Ashmore & Sabloff, 2002).

Again at Tikal, preference for north–south orientation was reiterated later in the eighth century as a grand cosmogram, extending a kilometer in each direction from the Great Plaza. That the "eastern" extension is not cardinally true likely reflects the presence of a swamp in that location, and without a modern map, the "inaccuracy" would not necessarily have been perceptible to participants in processions on the great roadways connecting the end points of the cosmogram. Similar cosmograms, at the same scale, are identified from about the same time at La Milpa, in northern Belize (Tourtellot, Wolf, Smith, Gardella, & Hammond, 2002), and at Copan, Honduras (Ashmore, 1991).

Each of these expansive expressions included paved roadways. These presumably served processions as part of centering and recentering the city, whether allowing all to participate directly or maximizing privileged participants' visibility to others assembled along the route (Maca, 2006; Reese-Taylor, 2002). The meaning of the city plan, however, would likely have been even more complex than suggested by the foregoing arguments. That is, while the proper disposition of royal precincts may have been paramount in some aspects of planning, there may have been complementary ways of "centering" the city or town. At Copan, for example, Maca (2006) suggests that periodic centering rituals involved progression along a path defining a rhomboid on the modern map of the ruins and neatly enclosing the area of densest Late Classic settlement. This kind of centering is not inconsistent with other aspects of planning, argued earlier as emphasizing a north–south axis of dynastic celebration (Ashmore, 1991).

Elsewhere, the scales of construction differed, as sometimes did the arrangement of positional symbolism. At Xunantunich, Belize, for example, Keller (2010) argues that the city plan is cruciform or a quincunx, cardinally oriented, and repeatedly given life by processions. As at Copan, the paths included paved roads, but the ones in this case were shorter in distance. Contrasts in scale at Xunantunich, Copan, and Tikal likely involved relative abilities to harness labor and material resources, the huge capital at Tikal differing most dramatically from the provincial city of Xunantunich. But Xunantunich differed from Tikal, as well, in the arrangement of plan elements. Both had strong north–south axes. As already noted, Tikal's Late Classic plan featured varied scales of the "twin-pyramid group" directional symbolism, with rulers metaphorically apotheosized through their portraits in northern positions. In contrast, at Xunantunich, royal portraits and ritual observances seem to have been located more toward the south end of the axis, at the monumental pyramidal building known today as the "Castillo." In this, and in overall appearance, the plan of Xunantunich is much more similar to those of its long-time overlord, Naranjo, and of Calakmul, the "superstate" far

to the north (Ashmore, 1998). Texts explicitly indicate inclusion of Naranjo in the extensive Calakmul alliance and assert that both were often, if not perpetually, in conflict with Tikal. It thus seems quite possible that the city plans of each place constitute nonverbal expression of political alliance at the point when the plan was commissioned (Ashmore & Sabloff, 2002).

In other places, town and city plans seem to reflect additional alternative models for assembling the elements described at the outset here. These distinct layouts, too, are ascribed to strategic choices and political affiliation. For example, de Montmollin (1995) describes a complex array of spatial arrangements in the settlements along the upper tributaries of the Grijalva River, in Chiapas, Mexico. None of them resembles the layouts described earlier, and de Montmollin attributes the regional variability, at least in part, to contrasting political histories of Maya and people of other cultural and linguistic groups resident in the area.

While Landa's concentric model for town layouts fits some pre-Hispanic settlements, like Classic period Dzibilchaltun (Kurjack, 1974), it has been rejected as a model underlying some other plans. Chase (1986) has written of the fourteenth-century site of Santa Rita, Belize – probably the capital of the historically known province of Chetumal – as organized in quarters but not concentric zones. For Copan, Stomper (2001) sees aspects of concentric settlement rings, quadrants, and the political upheavals of the eighth and ninth centuries as cumulatively shaping the plan of the city and the architecture designated by successive kings as the key symbolic components in the plan. This view differs from but is not incompatible with Ashmore's and Maca's views, described earlier. Once again, such assertions are more likely indications of the complexity of successive planning episodes and building programs in reflecting worldview than they are of any one analysis being either entirely adequate or entirely false.

That Maya cities and towns were planned seems clear (Andrews, 1975). Still to be explored is the full range of expressions by which planners adapted and residents enacted the fundamental principles governing establishment of orderly town and city space.

See Also

- ▶ Architecture of the Maya
- ▶ Architecture of the Maya: Public Architecture
- ▶ Astronomy in Mesoamerica
- ▶ Calendars in Mesoamerica
- ▶ City Planning: Maya City Planning
- ▶ Cosmology in Mesoamerica
- ▶ Knowledge Systems of Indigenous America
- ▶ Mathematics: Maya Mathematics
- ▶ Pyramids of Mesoamerica
- ▶ Temples of the Maya
- ▶ Time in Maya Culture

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City Planning in Ancient India

Paul Gregory

As the birthplace of Indian culture, the towns of the Indus Valley represent an important and rich source of information concerning urban development in the Indian subcontinent. The Indus River is one of the largest and most important rivers in south central Asia. From its source in the Himalayan Mountains to its terminus in the Indian Ocean it traverses a course of over 2,000 miles. For millennia it has been an essential route for travel, trade, and communication and has been the source of much of India's agricultural production. The valley which surrounds the Indus River has witnessed the birth, growth, and death of many cities.

Excavations of Indus towns have demonstrated the most ancient town planning in the world. The grid pattern (straight streets intersecting other straight streets at right angles) is among the most common and universal types of town planning. The discovery and excavation of the most famous of these sites, Mohenjo-daro, by Sir John Marshall (1931) and Ernst Mackey (1938) supported the contention of Dan Stanislovski (1946) that the development of the grid pattern in western societies – Greece, Rome, and Europe in the Middle Ages – can be linked directly to the development of town planning in the Indus valley.

A recent excavation on the Western plains of the Indus – the Rahman Dheri site – reveals a town plan from the early Indus period. This site comprises an area of roughly 22 ha and could have been home to 10,000–14,000 people. Radio carbon-dating of artifacts places development somewhere in the first half of the fourth millennium BCE. Rahman Dheri is built in the classic grid pattern. It is rectangular in shape surrounded by an immense wall and bisected by a major traffic artery which runs roughly southeast to northwest. Perpendicular to

this road exists a pattern of regularly occurring laneways which appear to create individual dwelling lots.

The successor to the plan of Rahman Dheri is thought to be the Surkotada site in Kutch which dates to ca. 2500–2000 BCE. Though smaller in scale than its predecessor the Surkotada site is built along the same grid pattern as Rahman Dheri. This settlement was enclosed by a stone rubble and brick fortifications. This produced two separate areas each of roughly 60 m^2.

Similar to Surkotada, only on a larger scale, the Kalibangan site was completely surrounded by an enormous rampart. This site, about 200 km to the southeast of Hirappa on the banks of the (now dry) Ghaggar river, was composed of two mounds. The smaller mound, named the citadel, was to the west and was roughly 240 m by 120 m. The larger mound, named the lower city, was to the east and measured 360 m by 240 m. The lower city demonstrates the grid plan divided into blocks of which the east-west side was roughly 40 m in width. The width of lanes and streets in the lower city ranges from 1.8 to 7.2 m. Interestingly each lane or street is some multiple of 1.8 m. This site is thought to date to the early Indus period, roughly 3000 BCE.

The evolution of Indus town planning reached its zenith at Mohenjo-daro. The town is geographically located on a floodplain of the Indus river; the city occupies about 1 km^2 – over five times larger than Kalabangan. The basic grid of Mohenjo-daro is about 180 m^2, subdivided into 16 sections of about 40 m^2. Mohenjo-daro existed from ca. 2500 to 2000 BCE. During this time it bore the brunt of often severe flooding, and as a result the original grid plan was often modified and transformed. The city itself was originally planned in the same way as Kalabangan: an oblong walled city divided into a citadel and a downtown area divided by an open space. Similar to its predecessor communities, the town plan of Mohenjo-daro indicates the same parallel grid street structure that has come to characterize urban planning in this region at this time.

As this brief history of the evolution of town planning in the Indus river valley demonstrates the grid pattern was commonplace. The importance of the Indus river valley communities to the historical development of culture and civilization in the Indian subcontinent and the East is well known. Stanisloski has suggested that the grid pattern form of town planning has its roots in the Indus valley. Parallel developments in Nepal, Sri Lanka (formerly Ceylon), Burma, Korea, Vietnam, and China also indicate how widespread the influence of the Indus river valleys communities were. It is suggested that this form of town planning was taken up by the Greeks, Romans, and other Western Europeans and eventually became a standard form of urban organization in Europe and the New World.

Excavations at and along the Indus River valley reveal cities strikingly similar in topography to contemporary Western European and North American cities. While some may suggest that the grid pattern evolved in a happenstance fashion without benefit of central planning or administration, substantial evidence exists to support the opposite point of view. First, the grid pattern can be seen in a variety of towns all along the Indus river, which existed and flourished over a several thousand year period. Second, the similarity between these towns and the general division between a lower city area suggests the development of town planning conventions as early as 2500 BCE. Third, there is a remarkable mathematical symmetry in Kalabangan where lanes and streets (which range from 1.8 to 7.2 m in width) all occur in multiples of 1.8 m.

The contribution of this historic period to the development of Western cities should not be underestimated. Much of what we take to be enlightened urban planning was considered over 4,000 years ago by planners in south eastern Asia.

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City Planning in Cambodia

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City planning in Cambodia has gone through four phases: (i) 800–1431 when Angkor was the capital of the Khmer empire, (ii) fifteenth to nineteenth century, (iii) during French colonial rule (1863–1953), and (iv) since independence.

City Planning at Angkor

The key concept that informed early Khmer city planning was the cosmological belief that symbolic correspondences existed between the divine macrocosm of the Hindu gods and the mundane microcosm. The Khmer believed that the flow of power from the former to the latter could be ensured by giving these correspondences material expression in the configuration of centers of power.

In Hindu cosmology, the gods live in a divine city atop Mount Meru, the axis of the world, presided over by Indra, king of the gods (Mabbett, 1983). The mountain is surrounded by annular seas beyond which are the continents of different shapes located in the four directions, the southern one being the triangle of India. The Khmer king was believed to be the representative of Indra on earth, presiding over his court in a city designed to replicate the divine city of Indra.

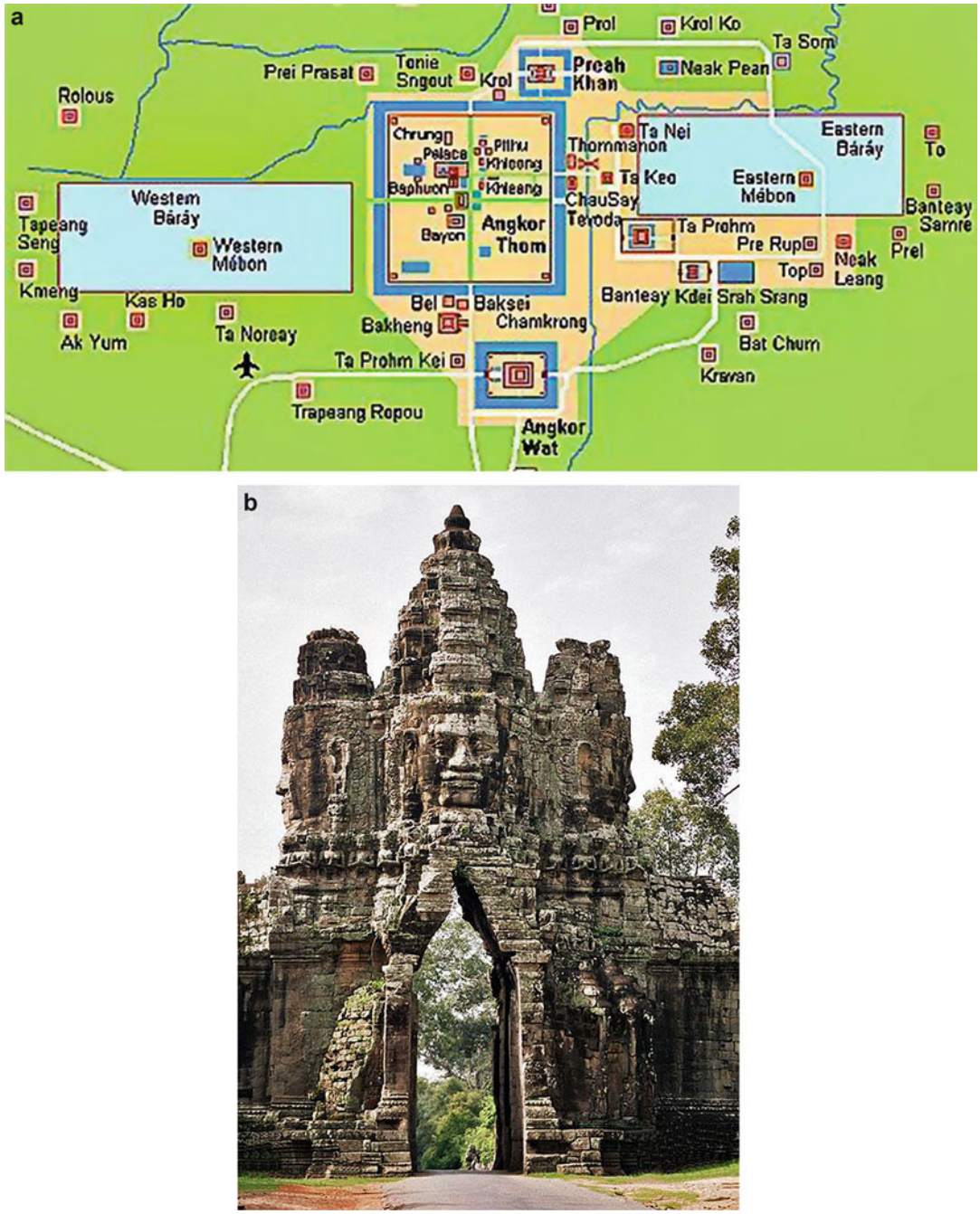
At the center of each of the sequence of royal cities constructed in the Angkor region, a temple mountain was built to represent Mt Meru. To the northwest stood the palace, while beyond were the fine wooden mansions of high court officials and further away the smaller houses of court retainers and artisans. Square walls surrounded the city, pierced by gateways in the four directions large enough for elephants to pass through, plus a fifth gateway reserved for the king. Beyond the walls, vast rectangular reservoirs (called *baray*) represented the seas ringing Mt Meru (Coe, 2003).

The last city, constructed by King Jayavarman VII in the late twelfth century, was Angkor Thom, "the great city", with walls 3.3 km long on each side (Fig. 1a, b). The central temples of earlier cities had been dedicated to the great Hindu god Śiva, but Jayavarman VII was a Tantric Buddhist. His central temple, called the Bayon, still represented Mt Meru but was dedicated to the bodhisattva whose huge faces stare out in the four directions from each of its many towers and identified either as Lokeśvara, Lord of the Worlds, or Vajrasattva (Sharrock, 2007). The extensive palace complex with its private royal temple was situated as usual to the northwest of the Bayon, while to the east of the palace, high terraces looked out over a large public space where the king reviewed parades (Jacques & Freeman, 1997).

City Planning from the Fifteenth to the Nineteenth Century

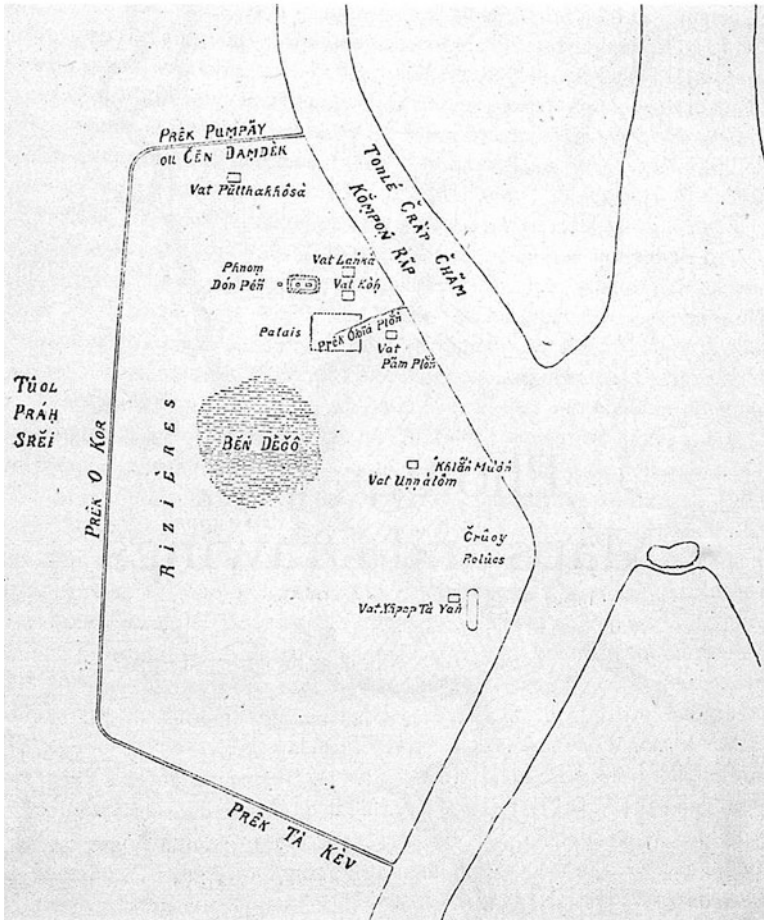
Angkor Thom was abandoned following a Thai invasion in 1431. By then, the Khmer people had adopted Theravada Buddhism, the center of population and productivity had shifted southeast toward the Mekong Delta, and seaborne trade was expanding (Chandler, 1993). Although the great days of the Khmer empire had long passed, Khmer kings were still considered semidivine – not because they drew their power from Hindu gods but because according to Theravada belief, they had accumulated great merit in previous existences. Their right to rule was reinforced by the merit they continued to acquire by generously endowing royal monasteries (Tambiah, 1976).

The new capital was situated at the point where the Mekong, Bassac, and Tonle Sap rivers converge, forming "four arms," in close proximity to a sacred hill known as the "Hill



City Planning in Cambodia, Fig. 1 (**a**) Angkor Thom. (**b**) Gateway to Angkor Thom

(*phnom*) of (Lady) Penh," which has given its name to the city of Phnom Penh. The new capital was not constructed as a square facing the four directions like Angkor Thom, but much Angkorean symbolism survived. In the temple atop the sacred hill, four Buddhas stared out over the four directions, and the long royal title bestowed on the city again



City Planning in Cambodia, Fig. 2 Phnom Penh in the fifteenth century. A sketch by G. Coedes 1913 (BEFEO)

referred to it as the city of Indra (Stuart-Fox & Reeve, 2011). The Phnom was thus clearly conceived as representing Mt Meru, the axis of Buddhist cosmography.

The royal palace was located not northwest of the Phnom, however, but downstream to the southeast and surrounded by a protective wall. Three new royal monasteries were constructed nearby (Cœdès, 1913) to accentuate the king's merit (Fig. 2). Phnom Penh was already a trading port, with the commercial area located downstream from the royal enclave, in accordance with planning principles adopted from Tai custom (see entry on "City Planning of the Lao/Thai"). The city was surrounded by an earth embankment and a moat comprising three straight sections.

The new Khmer capital incorporated the proper symbolic relationships in its planning, but it was not well defended and prone to inundation. Over the next two centuries, Cambodia was ruled from two new capitals constructed upstream, first at Lovek and then at Udong, both of which retained elements of traditional planning. Only after a new external power, France, offered protection in the face of Vietnamese and Thai encroachment, was the capital moved back to Phnom Penh.

City Planning Under the French

In 1865, 2 years after the establishment of the French Protectorate over Cambodia, King

Norodom relocated his capital from Udong to Phnom Penh. With the exception of a small concession granted to the French adjacent to the *phnom*, development of the town proceeded by royal directive (Lamant, 1991). Sacred urban space was organized to reflect the Khmer conception of the divine power of the king, just as it had been at Lovek and Udong. In the process, a riverine market town built of wood and thatch and dominated ethnically by Chinese and Vietnamese traders was transformed into a Khmer royal capital.

French influence on town planning evolved toward the end of the nineteenth century as a consequence of France's increasing political authority. A series of conventions and other legal agreements progressively transferred power from the king and changed local laws. By June 1884, French representatives had assumed almost complete control of the city's administration after forcing a new convention on Norodom under which private land titles were introduced, a municipal commission was created, and the French assumed considerable control over the collection of taxes and the passing of legislation (Muller, 2006). This was critical for investment and for providing a framework within which Phnom Penh could be developed as an expression of French power and economic interests.

In 1889, under the guidance of Résident Supérieur Huyn de Vernéville, work began on creating a French administrative enclave. Buildings for public works, a police station, offices for the Résident, a bank, and a treasury were just some of the impressive constructions to appear in stone, which in function and style helped assert the power of the colonial government. A large canal dug around the French quarter further segregated the area physically and symbolically from the rest of the city.

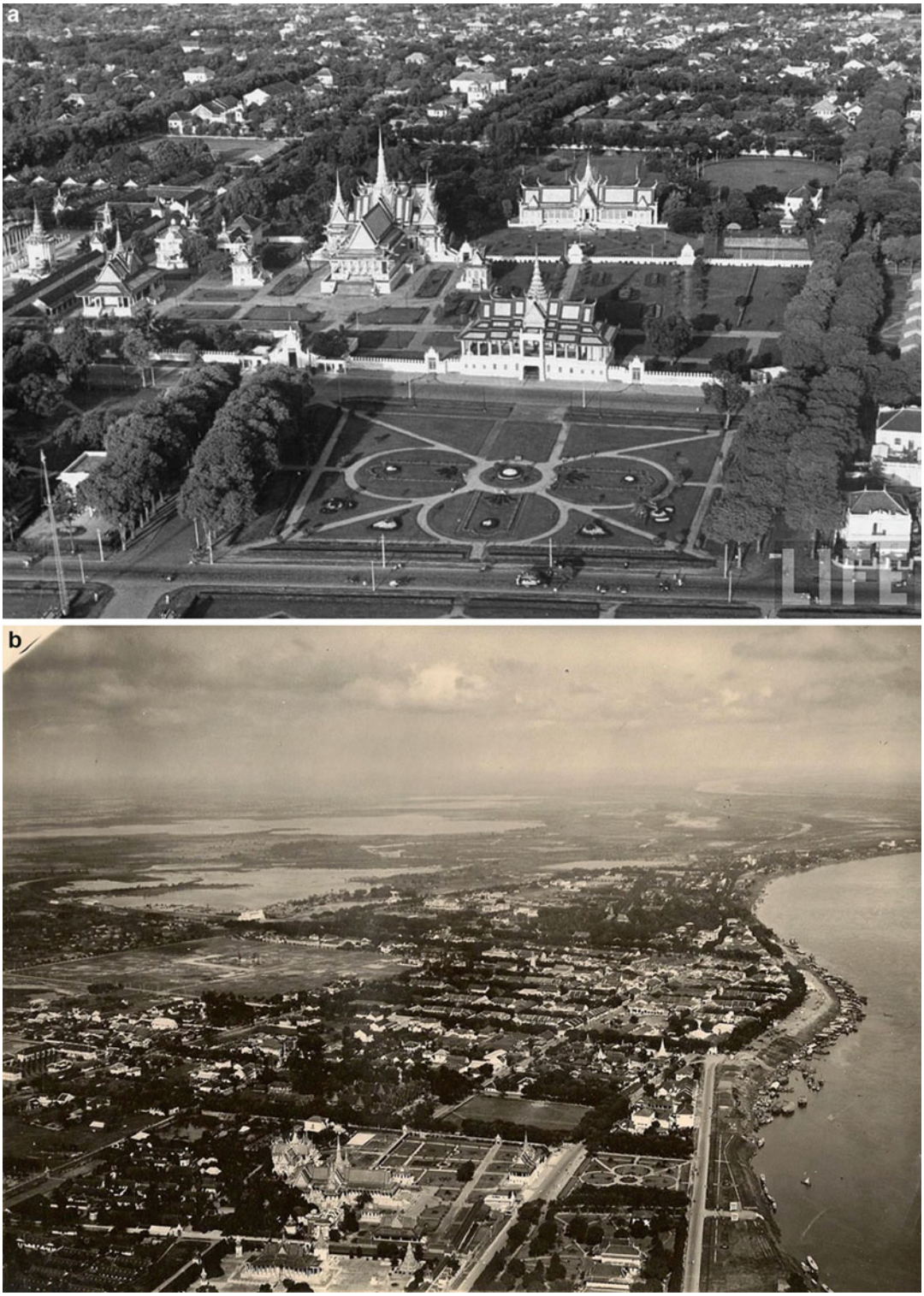
The rest of Phnom Penh was similarly divided into "quarters" defined largely along ethnic lines, which reinforced the de facto geography of the city. Immediately south of the French quarter was the city's economic heartland, dominated by the Chinese, while close-by was the Vietnamese quarter. The colonial government encouraged economic development through construction of a large covered market designed to move barter-based river trade on land, thus making it easier to both regulate and tax. By the end of the century, Chinese and French property speculators had fuelled a boom in the construction of shop houses that importantly provided confidence for the continued development of the capital.

The Cambodian quarter, centered on the royal palace, remained the cultural and spiritual center of Phnom Penh and indeed the kingdom (Fig. 3a, b). The royal Wats of Ounalom and Botum, the waters where the "four arms" converged and the sacred lake, were the sites of the rituals and festivals that went to the heart of what it meant to be Khmer. In the following decades, a museum, Pali school, a royal library, and the Buddhist Institute would reinforce the cultural orientation of the Cambodian quarter – and in Cambodian eyes, further reinforce the legitimacy of the monarchy.

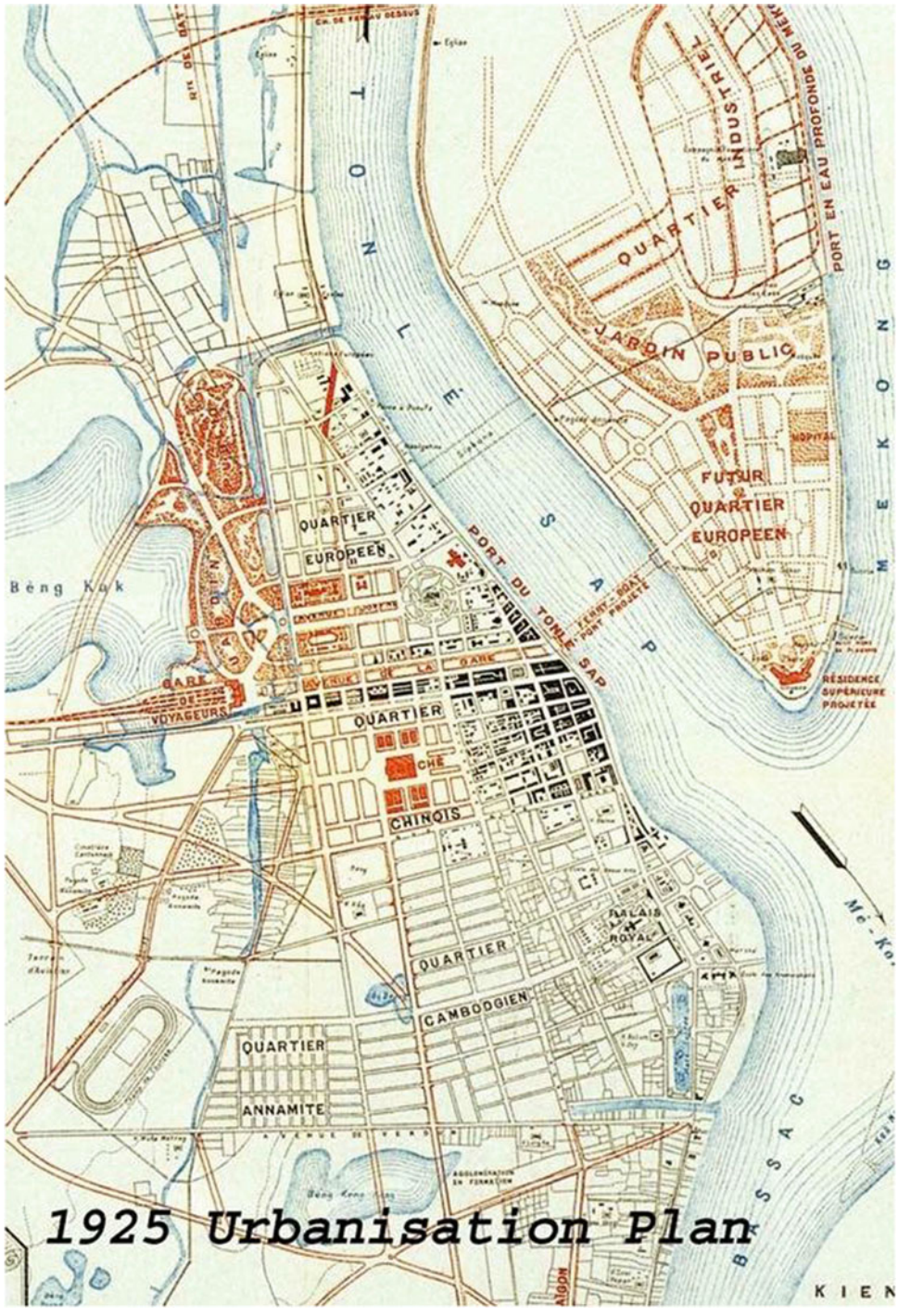
In 1925, Ernest Hébrard, an architect and town planner, formalized the layout of the city in his Phnom Penh Urbanization Plan (Fig. 4). The plan synthesized European concerns over hygiene and class/ethnic segregation with the need for modern infrastructure, economic zoning, and leisure space. Aided by the surveyors and engineers who had created firm footings from a flood plain, Phnom Penh developed rapidly to the north and west. By 1950, the framework, if not the substance of Hébrard's aspirational plan, had become a reality in the form of arterial boulevards, thus providing the foundation for a Controlling Plan that would help shape postindependence Phnom Penh (Igout, 1993).

Modern Cambodian City Planning: Sihanouk and Beyond

In 1953, town planning was not the first priority of newly independent Cambodia, nor its king, Norodom Sihanouk, but it remained a matter of interest and concern. Phnom Penh had been bequeathed an administrative infrastructure orientated toward France and an education system



City Planning in Cambodia, Fig. 3 (**a**) The royal palace c1934. (**b**) Phnom Penh c1934 looking north from the royal palace



City Planning in Cambodia, Fig. 4 Ernest Hébrard's Phnom Penh Urbanization Plan 1925

inadequate for the task of supplying the bureaucrats and technicians the country now required. Compounding these problems was a huge influx of rural migrants who had fled civil unrest in the countryside in the lead up to independence.

Initial development reflected these pressures and by the end of the decade, an ambitious program was underway for the construction of schools, universities, and ministries. A lack of space within the existing city forced expansion westward and many of these government buildings were constructed at the beginning of a 10 km boulevard linking the city with the airport. Early testament to the city's modernization was thus showcased to foreign visitors and diplomats. Less visible were the public housing projects in the newly created suburbs of Tuk Laak in the west and Tuol Kork further north.

Great strides were also made in road construction and public works, which essentially followed the Controlling Plan created by the Urban Technical Service in 1950. An uncompromising grid system of streets spread residential areas further west and south while a radial system of roads fanned out from Tuol Kork. Services also expanded to keep up with development. Drainage remained a priority, while water reticulation was extended. Between 1953 and 1965, electricity capacity increased fourfold. In just 17 years, from 1953 to 1970, Phnom Penh doubled its physical footprint (Fig. 5).

The most notable additions to the city were the formidable civic projects of the 1960s: the Bassac Riverfront development consisting of hundreds of apartments, a conference hall, and a national theater built on 24 ha of reclaimed land; the National Sports Complex – a vast sporting facility originally designed to host the 1963 Southeast Asian Games; and a myriad of other prestigious constructions (Fig. 6a, b). Conceived and designed by visionary Khmer architects such as Vann Molyvann and Lu Ban Hap in collaboration with foreign experts like the Russian engineer Vladimir Bodiansky, their work was made possible through the encouragement and generous patronage of Norodom Sihanouk, then head of state (Molyvann, 2003). Much of their work also reflected a style that was uniquely Cambodian giving us what is termed today "New Khmer Architecture" (Grant-Ross & Collins, 2006).

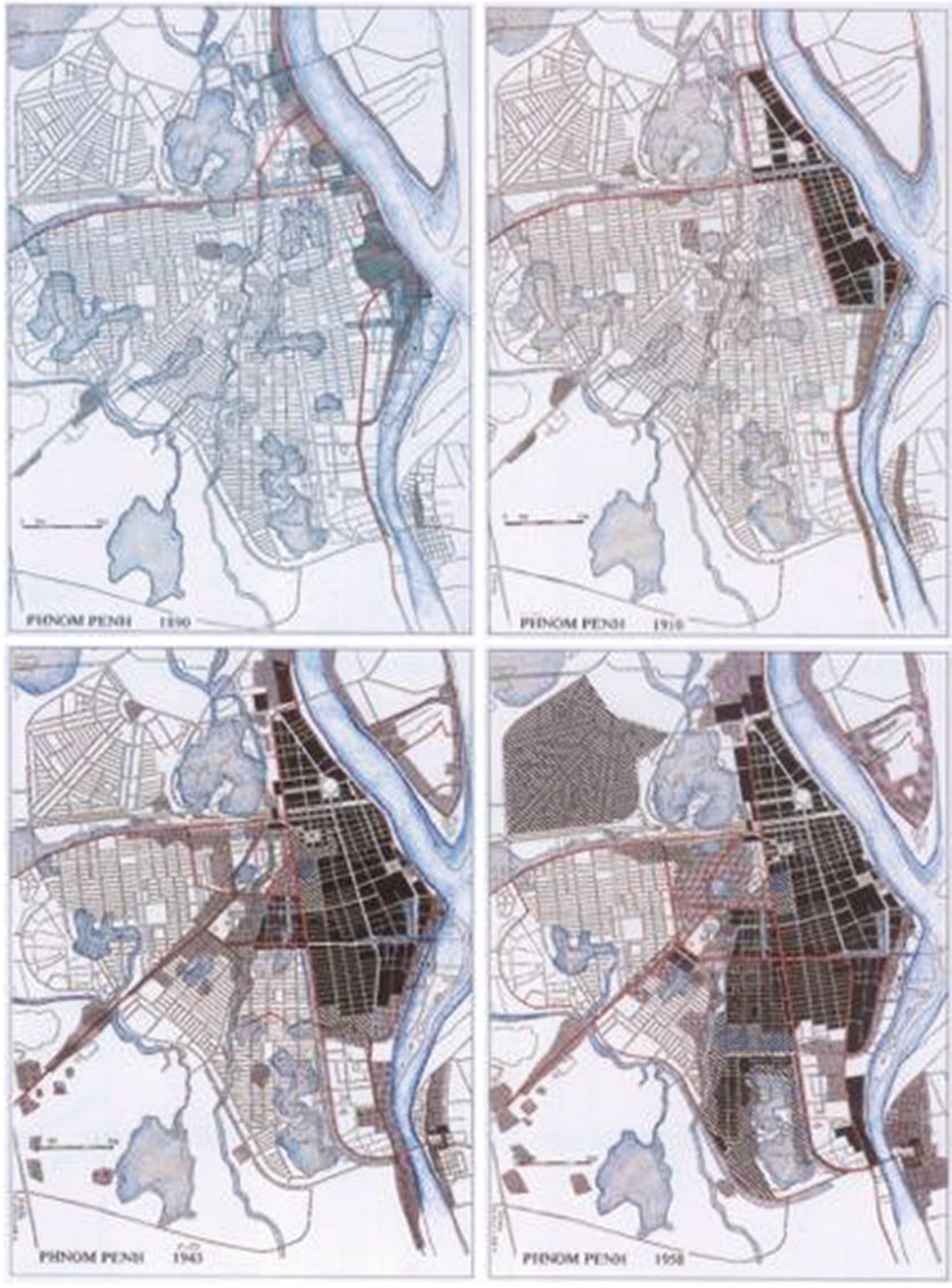
The departure of the French saw the administration move to new ministry buildings located throughout the city. The palace and royal temples, however, remained the locus of traditional culture, now united with the institutions of state power: the National Assembly, the Ministry of Justice, the Ministry of Foreign Affairs, and a new residence for the head of state (Atelier Parisien d'Urbanisme, 1997). The biannual National Congresses, which combined popular democracy with political theater, were held adjacent to the royal palace and reinforced popular belief in the relationship between Khmer culture and political power.

Migration into the capital from rural areas and provincial towns turned Phnom Penh into a Khmer city. The Chinese quarter persisted; however, as the center of commercial activity, its density alleviated to some extent by its westward extension and construction of new four- and six-story shop houses. New state-owned enterprises created on the northern and southern peripheries of Phnom Penh further encouraged the city's outward expansion (Goulin, 1966).

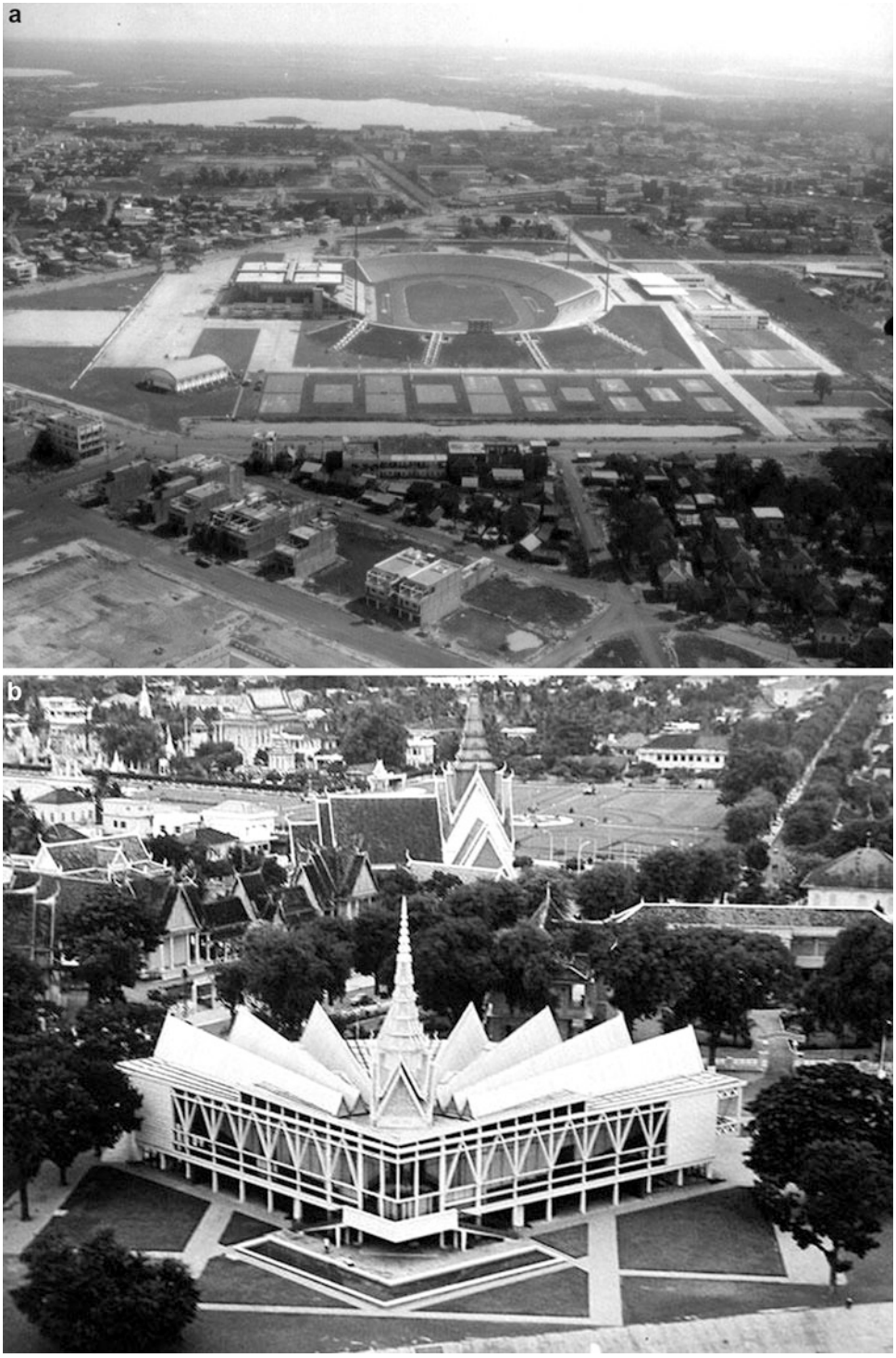
The rapid development and modernization of Phnom Penh owed a considerable debt to the vision and power of one man, Norodom Sihanouk (Osborne, 1994). Unfortunately, much of the development was overly ambitious, ill suited to the social and political aspirations of many of the city's residents and economically reckless.

Social tensions and economic difficulties contributed to the overthrow of Sihanouk's government in 1970, which plunged the country into civil war. Over the next 5 years, the population of Phnom Penh more than doubled as refugees poured in, and city planning was abandoned. Under the Khmer Rouge, the city was evacuated and was only slowly restored to life during the decade after the regime was overthrown.

With the United Nations administered peace agreement and 1993 elections, Phnom Penh entered a period of rapid and uncontrolled growth, which led to the destruction of many old buildings (Igout, 1993). A comprehensive



City Planning in Cambodia, Fig. 5 The progressive development of Phnom Penh, 1890, 1910, 1943, and 1958 superimposed on a 1968 outline of the city



City Planning in Cambodia, Fig. 6 (**a**) The National Sports Complex 1964. (**b**) Modern Khmer Architecture: Chaktomuk Conference Hall, inaugurated 1961

plan for the city's future drawn up by French urban planners was submitted to the Cambodian government, but not ratified. In the meantime, land grabbing, forced eviction, corruption, and profiteering continued to penalize the poor, shrink public space, pollute the environment, and destroy the city's architectural heritage.

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City Planning in India

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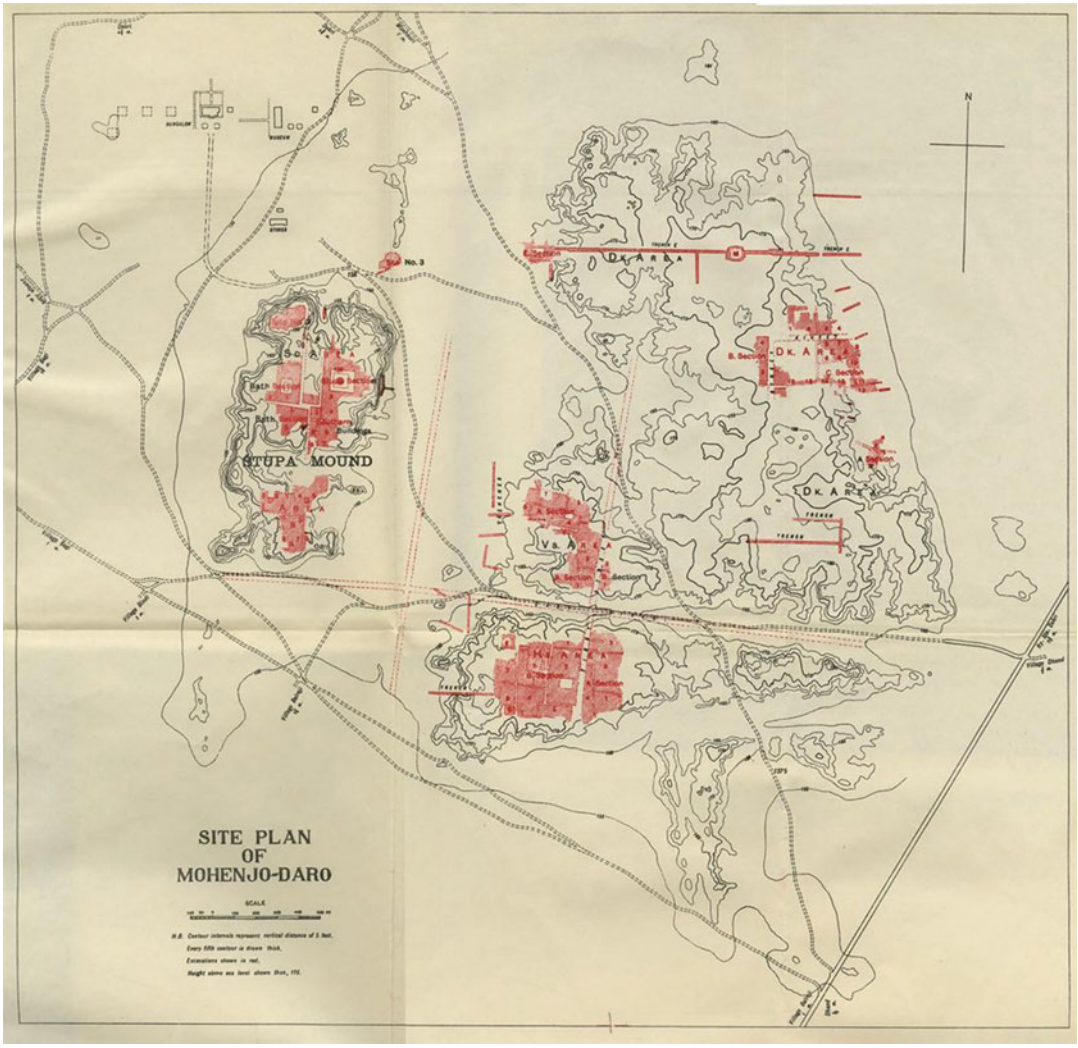
Ancient Town Planning

Those in search of origins tend to trace the history of urban planning in India back to the cities of the Bronze Age Indus period (2600–1900 BCE). Defined by rectilinear streets and supported by a well-developed infrastructure, cities such as Dholavira, Ganweriwala, Mehrgarh, Harappa, and Mohenjo-daro (but particularly the last two) sit at the center of India's city planning heritage.

Excavations of Indus Valley Civilization archaeology, beginning at Harappa in 1921 and continuing today, have revealed a network of interconnected cities, towns, and villages stretching from the Arabian Sea to Afghanistan. Distributed along the banks of the Indus River and its present-day tributaries, the Sutlej, Jhelum, and Ravi Rivers, Indus Valley cities featured high-density residential areas, large-scale monumental architecture, and efficient water supply and sewage systems (Jansen, 1989). Streets were oriented to the cardinal directions and connected the gates of the fortified perimeter walls to the city center. The best preserved of the cities, Mohenjo-daro, covered some 600 acres and consisted of several spur neighborhoods to the south and east of the main body of the city (see Fig. 1; Marshall, 1931). Because of Mohenjo-daro's location on a floodplain, the buildings and streets were raised on mounds. A variety of materials were used to build Indus Valley architecture, including stone, mud, mud brick, and baked brick. The buildings and walls of Mohenjo-daro were constructed mostly of baked mud brick, supplemented with wood, Indus rushes, burnt brick, and mud. The city's extensive system of roads and lanes was fronted by mud brick walls interrupted only occasionally by doors, seldom by windows (Possehl, 2002, pp. 99–110).



City Planning in India, Fig. 1 Plan of Mohenjo-daro based on archaeological excavations conducted 1922–1927 (Marshall, 1931, endplate)

Mohenjo-daro's archaeological remains are dominated by the Mound of the Great Bath. Walls of baked brick braced this elevated area, which served as a platform for the city's symbolic architecture, including the so-called Great Bath, a large burnt brick tank surrounded by verandas, and the Warehouse, a single-story building constructed of wood with a mud-and-rush roof. Scholars suggest the two structures were located intentionally near each other. The warehouse stored objects for the personal use by the bath keepers but probably also held goods to distribute as part of their role as patrons. Those responsible for the design of the Mound of the Great Bath understood the symbolic potential of anchoring the city with monumental architecture marked by privilege (Possehl, 2002, pp. 185–192).

At the same time, fieldwork carried out by archaeologists from the Rheinisch-Westfälische Technische Hochschule of Aachen under the leadership of Dr. Michael Jansen contradicts the long-held assumption that the urban form of

Mohenjo-daro and other cities of the Indus Valley Civilization derived from a master plan. It is more likely that the cities grew organically from smaller mud brick houses with accompanying storage areas (Kenoyer, 1998). However, the investment in water management systems, ranging from wells adjacent to housing compounds, to private baths in almost every house, to the monumental Great Bath, suggests that some forethought was given to both the engineering and symbolic potential of infrastructure.

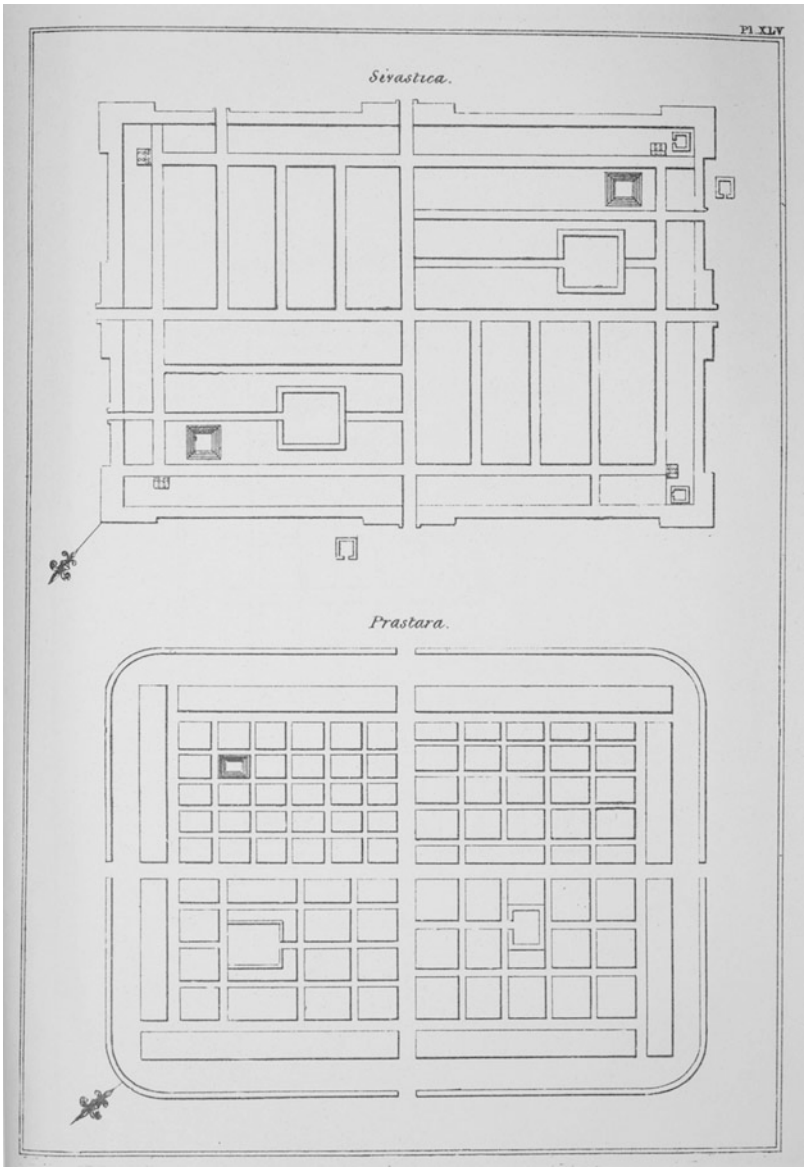
At roughly the same time that the cities of the Indus Valley Civilization were being established in the northwest of the subcontinent, the earliest conventions governing urban planning appeared in south India. The first known reference to building – an invocation of the protector of the house, or *Vāstospati* – is found in the *Ṛgveda* (c. 1500 BCE), but the rules of building and design, known as the *Vāstu Śilpa Śāstras*, developed from the Sthapatya Veda, which was a subset of the Atharvaveda (c. 900 BCE) (Rao, 1998). The *Vāstu Śilpa Śāstras*, which can be understood as mental constructs or idealized building codes, covered at least five distinct subjects: engineering, town/urban planning, secular or civil architecture (middle-class residential buildings), palace architecture, and temple architecture (Shukla, 1993). Today, the *Vāstu Śilpa Śāstras* exist only in secondary form; major works such as the *Mānasāra* (450–550 CE) and the *Mayamatam* (1000–1100 CE) have been recompiled from fragmentary texts by scholars in the nineteenth and twentieth century.

Ram Raz was the first to publish a scholarly examination of the *Vāstu Śilpa Śāstras* in 1834, and it is from him that we receive many of our ideas about urban planning in ancient India. His treatise, based on the "shattered remains" of the *Mānasāra*, *Mayamatam*, *Kaśyapa*, and *Vaikhānasa*, described the rules of village and town planning that he had extracted from the remains of ancient texts (Raz, 1834, p. 3). According to his analysis, the *Mānasāra* outlined the 8th village is cārmuca *dandaka* ("that which resembles a staff"), *sarvatobhadra* ("in every respect happy"), *nandyāvarta* ("the abode of happiness"), *padmaka* ("that which has the form of a lotus flower"), *sivastica* ("that which resembles the mystical figure so named"), *prastāra* ("that which has the shape of a conch"), and *chaturmukha* ("that which has four faces"). Despite the ornamental names, the plans adhered to a standard pattern, with rectangular or oblong site plans, situated such that the north–south line ran diagonally through the city (see Fig. 2). Each village had four gates that opened onto a network of parallel streets. Neighborhoods were zoned according to occupation, with residents separated along class and caste lines (Raz, p. 41).

Early Modern Town Planning

Although sometimes formally similar to the idealized plans depicted in the *Vāstu Śilpa Śāstras*, the cities of early modern India (1562–1750 CE) were shaped more by social custom and landscape conventions than by Vedic theory. For example, the Timurid "fourfold" garden (*chārbāgh*) and hierarchy of the military camp both contributed to the organizational strategies of the Mughal imperial capitals of Agra, Shahjahanabad, Lahore, and Fatehpur Sikri. Most of the cities can be read as incursive forms, in that the Mughals established their political centers in established urban centers, reshaping the existing urban fabric to suit their needs.

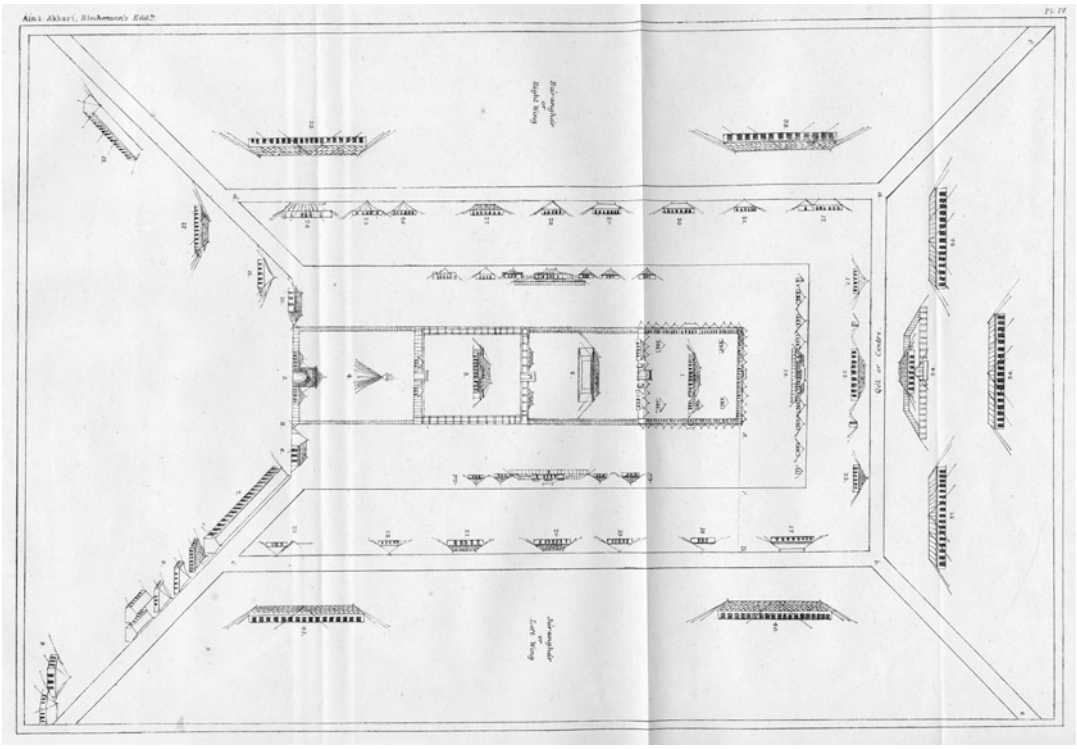
The Timurid (or Khurasani) *chārbāgh* arrived in India with the conquest of the Lodi Dynasty by the first Mughal emperor, Zahir-ud-din Muhammad Babur (1483–1530). After vanquishing the Lodis from their capital in 1562, Babur laid out a *chārbāgh* on the banks of the Yamuna River opposite the Agra Fort (Thackston, 2002, pp. 363–364). The walled garden was defined by modular parterres separated by elevated walkways (*khiyābān*) and cross-axial canals (*nahr*). Typically anchored by a pavilion or tomb, the garden was experienced as a series of framed scenes and pleasurable sensory experiences. After 1558, when Emperor Akbar (1542–1605) moved the imperial capital from Delhi to Agra, the *chārbāgh* became the defining feature of the



City Planning in India, Fig. 2 Ideal plan, *prastāra*-type village (Raz, 1834, Plate 45)

riverbank city (Koch, 1997, 2005). Walled gardens disciplined the floodplains on both sides of the river. By the reign of Jahangir (1569–1627), some thirty-three gardens stretched along the river (Pelasaert, 1925, p. 5). The gardens provided privacy for political intrigue as well as sheltered social space for the women of high-ranking families.

As Ebba Koch points out, eventually the *chārbāgh* was released from its riverfront moorings, becoming the main module for planning imperial cities (Koch, 1997, p. 144). The riverfront gardens of Agra influenced the disposition of royal spaces in Delhi and Lahore (Rehman, 2009). Some Mughal cities exhibited a rectilinearity generated not by the adaptation of garden principles but by the influence of military encampments. The imperial camp was laid out in a rectangular scheme, with the most privileged spaces – the imperial harem, Hall of Special



City Planning in India, Fig. 3 The Mughal imperial encampment (‘Allami, 1873, Plate 4)

Audience (*Diwān-i Khās*), and Hall of Ordinary Audience (*Diwān-i Ām*) – occupying the center line. Entrance into these tents was via the Drum Room (*Naqqar Khāna*). Surrounding these tents on four sides, creating an effective barrier between the imperial halls and the encampments of the princes and amirs, were lines of storehouses, guardhouses, and kitchens. The higher the rank of the prince, the closer his tent could be pitched to the imperial center (‘Allami, 1873; Blake, 1991). The distribution of tents, arranged according to imperial rank, was replicated in the built environment of the great Mughal cities (see Fig. 3).

Founded c. 1571, Akbar’s second capital of Fatehbad & Saleem (present-day Fatehpur Sikri) lay west of Agra at a site sanctified by the tomb of the Chishti saint, Shaikh Saleem. Constructed on a ridge, the city was organized around multiple axes running parallel to each other. The inspiration for this arrangement came from the logic of the military encampment and the quadrilateral form of the Hall of Ordinary Audience (Petruccioli, 2007; Rezavi, 2013). Central to Fatehpur Sikri’s success was Akbar’s deployment of water management technology. Legend reports that Akbar abandoned the city because of water shortages, but recent scholarship on hydraulics indicates that the city was supplied with potable water by a large lake at Sikri (now dry) as well as a series of wells (*chāhs*) and stepwells (*bāolis*) (Petruccioli, 2007; Rezavi, 2013). The extensive system of canals and quadrilateral reservoirs provided visual and aural delight to the city’s inhabitants while emphasizing the sharp lines of the architecture.

Perhaps the greatest Mughal imperial city, Shahjahanabad, was constructed by Emperor Shah Jahan (1592–1666) on the banks of the Yamuna River in Delhi. Shah Jahan, who had made limited improvements to the palaces and gardens of Lahore and Agra, decided to build a new capital c. 1638. The plan of Shahjahanabad drew on both garden and encampment

precedents. The city was constructed from east to west, beginning with a palace sector on the western bank of the Yamuna (Krafft & Ehlers, 1995). The city was walled in 1651–1658. Monumental gates in three walls (the fourth wall was fronted by the river) controlled vehicular and pedestrian access to the inner neighborhoods and imperial palace. Although irregularly shaped, Shahjahanabad was centered on the long axis of the main bazaar street, Chandni Chowk, which ran from the Kashmiri Gate in the west to the Lahore Gate of the Red Fort (Lal Qila) in the east. Built in 1650 by Jahanara Begum, Shah Jahan's eldest daughter, Chandni Chowk was 40 yards wide and 1,520 yards long (Blake, 1991, p. 55). A canal, flanked by two rows of streets, ran the length of the bazaar. Despite the number and variety of shops lining Chandni Chowk, the street front maintained an architectural uniformity, with roof lines kept at a uniform height.

Shahjahanabad's social and physical fabric was largely determined by the same hierarchical relationships that governed the military camp. The disbursement of land to princes and amirs for the construction of walled courtyard mansions (*havelis*) came by imperial grant. In return for land revenue, nobles were expected to provide loyalty and military support to the empire. Daily life in the *haveli* was shaped by hierarchical relationships as well, as each amir sat at the apex of a patriarchal pyramid. The body of the pyramid, which comprised laborers, artisans, soldiers, and servants, could encompass thousands of individuals, all living within the walls of the compound (Hosagrahar, 2001).

Ostensibly an imported Mughal form, the *chārbāgh* also affected subimperial urban planning. For instance, the city of Jaipur, founded in November 1727 by the Rajput king Sawai Jai Singh II (r. 1699–1743), owes it rectilinear form to the garden at its center. Established c. 1713, Jai Niwas Bagh, a quadripartite garden that measured some 1,740 ft long (exclusive of its water tank, Talkatora) and 450 ft wide, served as the module for the city's neighborhoods. As the city grew, boulevards and bazaars were laid parallel to Jai Niwas Bagh's walls. The distance between the roads and size of the blocks took their cues from the garden's scale and proportions (Johnson-Roehr, 2013).

Colonial Town Planning

With European settlement in India came European spatial structures. The earliest colonial towns were military suburbs, built beyond the walls of extant cities such as Lahore, Ahmedabad, and Bangalore. These planned enclaves, known as cantonments (or civil lines when designated for use by senior officers), followed military logic, with spaces defined in terms of rank and race. Streets were ordered and regular, laid out in parallel lines and gridiron formations, and were typically oriented to the cardinal directions. Often the plan centered on a park (*maidan*), which was in turn defined by the structure of a significant cultural institution, such as an Anglican church. Senior officers lived in the center of the cantonment; residences of lesser officers surrounded this core according to military rank. Native troops – infantry and cavalry – were housed in barracks at one end of the cantonment, while British troops occupied the opposite reach.

Cantonments and civil lines were intended to segregate European (read: white, British) military personnel from the perceived threats of Indian life (Cherian, 2004; Glover, 2008; Wald, 2012). The suburbs were functionally zoned, with residential spaces separated from stables, markets, and rifle ranges, but they were also arranged so as to separate "camp followers" (water carriers, cooks, petty officers, etc.) from British soldiers. Laws such as the Cantonment Act of 1864, which governed the sale of alcohol and drugs within cantonment markets, and the Contagious Diseases Acts of 1864, 1866, and 1869 reassured an anxious British ruling class that contagion could be contained through urban planning and legislation.

Recent scholarship demonstrates that the notion of a "white town" was in large part a fiction, maintained by the British as means of coping with the perceived difficulties of their

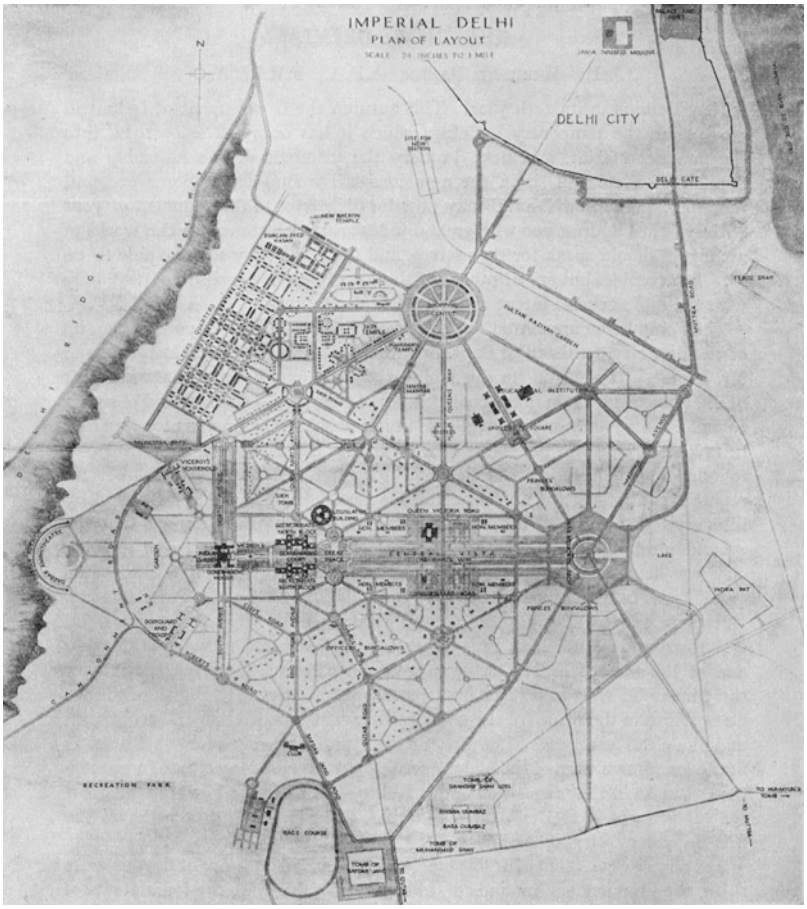
daily lives (Chattopadhyay, 2000). In some instances, local agents were deeply embedded in the process of shaping the city. This was particularly true in colonial Bombay, where Indian philanthropists contributed to the design and construction of civic and public institutions. The construction of the Gothic Revival buildings at the University of Bombay (Mumbai), Crawford Market, and the School of Practice (now Sir J. J. Hospital), buildings which formed the core of the city's colonial landscape, was made possible only by large donations from noted Parsi philanthropists such as Sir Jamsetjee Jejeebhoy (1783–1859), Sir Cowasji Jehangir Readymoney (1812–1878), and Premchand Roychand (1831) - (Chopra, 2011).

The most dramatic example of colonial urban planning came with the George V's proclamation at the imperial durbar of 1911 regarding the imminent transfer of the British capital from Calcutta to Delhi. The announcement was an attempt to undo the political damage done to the Raj by the Bengal Partition in 1905. The partition had aimed to cool nationalist fervor by dividing the region according to religion (Hindu and Muslim). However, it instead gave the independence movement a concrete point of contention. As part of the larger project of creating a new capital at Delhi, the British government reunified Bengal and established Calcutta as a provincial seat, hoping to quell the growing discontent of the Indian National Congress.

Drafted initially by the trio of British architect Edwin Lutyens, London County Councillor George Swinton, and civil engineer John Brodie, the plan of New Delhi drew equally on the Garden City and City Beautiful movements, both of which responded to the industrialization and urban crowding of the late nineteenth century. Garden City theory evolved largely in the British context. Initiated in 1898 by Ebenezer Howard, the movement valorized the self-contained satellite city (Howard, 1902). Envisioned as a blend of the best elements of town (cultural institutions, good wages, employment) and country (fresh air, beauty, low rents), the Garden City was proximate to a major city but surrounded by a greenbelt and economically self-sufficient. The aesthetics of the Garden City echoed those promoted by City Beautiful advocates, whose work came to full fruition in the United States. Led by architect Daniel Burnham and landscape architects Frederick Law Olmsted, Sr. (and later Frederick Law Olmsted, Jr.) and embraced by firms such as McKim, Mead and White, the City Beautiful movement prized Beaux-Arts architecture and planning principles (Olmsted, 1911). Put on public display for the first time in the plan and pavilions of the 1893 World's Columbian Exhibition, the movement's neoclassical buildings and cross-axial boulevards soon dominated American urban planning. Between 1902 and 1905, Burnham's office created City Beautiful plans for Washington, D.C., Cleveland, Manila, and San Francisco (Burham & Bennett, 1909). Regularity, proportion, and a Beaux-Arts formality were combined with transportation management and the restructuring of leisure spaces to create a largely horizontal, largely neoclassical, modern city.

The New Delhi plan combined these two schools of thought, calling for an expansive urban development south of walled city of Shahjahanabad. The desire for political pomp and drama led to a plan featuring broad boulevards pinned by outsize traffic circles (see Fig. 4). Although the scale of construction makes it difficult to discern at ground level, New Delhi was oriented along a west–east ceremonial axis, Rajpath (today's Central Vista). At the west end of Rajpath stood the Viceroy's Residence (today's Rashtrapati Bhavan, or President's Residence). The Secretariat (today's North and South Blocks) flanked Rajpath just east of the Viceroy's Residence. Originally, a commemorative column was to mark the east end of the ceremonial axis. Today, India Gate rises at the center of the hexagonal roundabout that marks the boundary between the colonial development and the ancient city of Delhi as represented by the Purana Qila.

Several village settlements were displaced to build the city, but in an attempt to legitimate the British claim to rule, several Mughal monuments were incorporated into the plan. The southern terminus of the city was marked by Lodi Gardens



City Planning in India, Fig. 4 Layout of New Delhi (Baker 1926, p. 774)

and the mid-eighteenth-century Safdarjung's Tomb. The remnants of the Jantar Mantar, an astronomical observatory constructed by Sawai Jai Singh II, were turned into an archaeological park just south of New Delhi's original commercial circus, Connaught Place. To the east of New Delhi were Purana Qila and Firoz Shah Kotla. The northern boundary of the city was controlled by the walls of Shahjahanabad.

Although New Delhi was the most visible evocation of Garden City theory in India, the movement shaped the work of other colonial era planners as well. For instance, Patrick Geddes, who composed town planning reports for some eighteen Indian cities between 1915 and 1919, promoted many of Howard's "town and country" ideas (Geddes, 1918; Tyrwhitt, 1947). In the typical Geddes planning report, the emphasis was on open space, gardens, and playgrounds, and the retention (or recreation) of the village scale in the urban environment. Like many modernists, Geddes placed his faith in the diagnostic survey, considering it key for planning "the right places for each sort of people; places where they will really flourish" (Geddes, 1915a, p. 91). A thorough study of "the whole set of existing conditions" would permit British and Indian rulers to conduct what Geddes described as "conservative surgery," or the modification of existing urban fabric through targeted, rather than wholesale, demolitions or implementation of gridiron plans (Geddes, 1915b, p. 17).

Modern Town Planning

In the Independence era, Indian town planning was shaped by two forces: disaster management

(the urgent need to house post-Partition refugees) and urbanization (as a factor of and response to planned industrialization). In this setting, urban planning was intertwined with development discourse and a valorization of "scientific" management of human and material resources.

Exemplary of this approach were the steel towns and political capitals planned with the input of Otto Koenigsberger (1908–1999). Koenigsberger, who worked as the Government Architect for Mysore before accepting an appointment as the director of Housing for the Government of India, consulted on the plans for several new towns, including Jamshedpur, a company town managed by Tata Iron and Steel Company Limited (TISCO), and Bubaneshwar, the new capital of the state of Odisha. Koenigsberger's interventions at Jamshedpur (1943) and his plan for Bhubaneswar (1949) relied on the fusion of two devices: the *neighborhood unit*, a design module promoted by American planner Clarence Perry but used most recently in the 1943 Plan for Plymouth, England, and the *linear city*, which called for the distribution of neighborhood units on either side of an arterial road. Koenigsberger argued that the neighborhood unit, which could contain houses and services to support up to 18,000 people, would most closely replicate the physical and social conditions of the village. By distributing the neighborhood units along a main artery, he hoped to keep fast-moving traffic out of the residential areas while providing citizens access to undeveloped green space on the outer edge of the neighborhoods (Koenigsberger, 1952).

Koenigsberger's town plans competed for attention with the urban initiatives conducted in the Punjab, namely, the modernist state capital, Chandigarh. With the partition of India and creation of Pakistan also came the division of the Punjab. Lahore, the historical capital of the region, fell outside India's new boundaries. In 1948, the Government of Punjab appointed a committee to assess existing towns for their suitability as a new capital. The committee rejected all the candidate towns and hired the American firm of Mayer and Whittlesey (later Mayer, Whittlesey and Glass) to prepare a master plan for a new city. Chandigarh, a fully planned city at the foothills of the Himalayas, would serve as Punjab's political capital, but it was also meant to convey India's modernist aspirations to the world at large.

The first master plan was drawn up by Matthew Nowicki, a faculty member of the North Carolina State College School of Design who was an associate at Mayer and Whittlesey. The fundamental form giver of the city was to be the *superblock*, a walled, self-sufficient neighborhood unit consisting of low-rise single-family dwellings and terraces clustered around a central market-cum-service center. Each superblock contained four neighborhoods, the residences of which were tied to the government pay scale. Three neighborhoods in each block were designated for lower- to middle-class government workers; the fourth was prepared for the wealthier employees. This rationalization of space into a system of superblocks was balanced by Mayer and Nowicki's incorporation of the site's topography into the plan. The boundaries of the city were formed by the paths of two rivers, and two drainage valleys within the city proper were to be retained as green space that flowed through the superblocks. The major boulevards would be curvilinear, echoing the riverine topography (Evenson, 1966, pp. 19–24).

The Mayer and Nowicki plan was abandoned by the Government of Punjab after Matthew Nowicki's death in a plane crash in August 1950 (Mumford, 1954). A new design team, lead by Le Corbusier, Pierre Jeanneret, Jane Drew, and Maxwell Fry, took over the task of creating and implementing a master plan. The European team retained several features of the Mayer and Nowicki plan, such as the superblock (rechristened as a *sector* and re-proportioned according to the golden section), but the sectors were framed by a more rigid, straight-line city structure (Koenigsberger, 1953; Perera, 2004). The

gentle curves proposed by Mayer and Nowicki were replaced by a system of boulevards that adhered to Le Corbusier's theory of "the Seven Vs" (*les sept voies*, the seven ways). The Seven Vs sorted traffic according to speed, limiting high-speed vehicles to arterial roads (V1) and major high-speed boulevards (V2) and shunting slower traffic to pedestrian and bicycle paths (V7 and the newly invented V8) (Le Corbusier, 1961). The final city plan was determined as much by the relationships between automobile and pedestrian, point of origin, and destination, as it was by the city's political purpose.

Many of Chandigarh's major buildings were completed by a cadre of Indian architects, designers, and planners who worked under the guidance of M. N. Sharma. After Pierre Jeanneret returned to Europe, Sharma took control of the project, becoming the first Indian Chief Architect of Chandigarh. Aditya Prakash, A. R. Prabhawalkar, U. E. Chowdhary, J. S. Dethe, B.P. Mathur, and N. S. Lanbha, among others, brought to completion theaters, factories, educational institutions, and hostels.

Although Chandigarh influenced Indian city planning, serving as a model for other post-Partition capitals such as Gandhinagar, it played little role in one of the country's largest urban development initiatives, the planning and construction of Navi Mumbai (New Bombay). Bombay had long suffered from a land shortage. The original seven islands of the city had been brought together as one through various land reclamation projects in the nineteenth and twentieth centuries, but no one project was capable of changing the basic topography of the city. In post-Partition era, when the city experienced an influx of refugees, the solution had been to retain the industrial center in the south of the island while expanding residential districts in the north. This created increasingly lengthy commutes that, which were often made longer by an overburdened infrastructure. Many workers chose to live closer to their place of employment in the south of the island, but unable to afford property, they resorted to squatting on open land.

By the 1960s, it was clear that northern expansion was reaching its limits. A number of solutions had been proposed at the city and state level, but none had relieved the pressure on the north–south transportation corridor or the densely populated slums in the center of the city. In 1964, architect Charles Correa, together with engineer and planner Shirish Patel and structural engineer Pravina Mehta, submitted a proposal to the Bombay Municipal Corporation. In order to relieve the pressure on the north–south corridor, they suggested the city develop its east–west axis. The city should look east, across Bombay Harbor, to the mainland, where there was space for new construction. While the manufacturing heart of the city could remain on Bombay Island, government offices, the shipping industry, and white-collar workers would move across the water to New Bombay (Patel, 1997).

The proposal made by Correa, Patel, and Mehta reached the public courtesy of *Marg*, a magazine dedicated to both the preservation of traditional arts and the dissemination of modernist theory (Correa, Mehta, & Patel, 1965). A mixture of romantic dreaming and rational planning, the proposal garnered public approval, so much so that by 1971, the City and Industrial Development Corporation (CIDCO) was formed to build New Bombay. Charged with creating residences and infrastructure to support an initial population of four million, Correa, Patel, and Mehta, in concert with Chief Planner, R. K. Jha, drew on Ebenezer Howard's Garden City theories. Enough land was acquired to establish 14 satellites towns (or nodes), connected with a network of new infrastructure (highways, rail lines, bridges). The development of housing (low- and mixed-income cluster developments, luxury high rises) and service sectors (banking, hotels, markets) was divided between private parties, and the Navi Mumbai Municipal Corporation (NMMC) was established in 1991 to support the construction of the city.

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City Planning of the Lao/Thai

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The closely related dominant ethnic groups in modern-day Laos and Thailand both belong to the broader ethnolinguistic group of people speaking Tai languages that extends into northwestern Vietnam and southern China. Small bands of Tai began migrating out of southern China into what are now Laos and Thailand from around the eighth century on. As they took possession of fertile river valleys, they established small principalities (called *muang*) dominated by powerful aristocratic families who differentiated themselves from the commoners over whom they ruled (Condominas, 1990). These social distinctions determined how their principal settlements were planned, in relation to the flow of the rivers on which they were constructed.

In northern Laos, the Lao displaced Mon/Khmer-speaking subsistence farmers. But further south in Laos and in northern and central Thailand, Tai expansion encountered advanced civilizations in the form of Mon and Khmer kingdoms, whose capital cities incorporated quite different planning principles. Lao, and more especially Thai, city planning evolved as an amalgam of traditional Tai and borrowed Mon/Khmer organizing principles, which in turn derived from both Hindu and Theravada Buddhist cosmological beliefs.

The Principles of Traditional Tai Planning

The Tai peoples were originally animists. They believed that the natural world was inhabited by a vast array of spirits (known as *phi*), which needed to be propitiated. Particularly dangerous were dragon-like monsters called *ngeuk* that lurked in the rivers in which they fished, tipped over canoes, and sucked the blood from the drowned. *Ngeuk* that accepted Buddhist teachings, however, became protective *naga*, about which an extensive mythology was developed (Ngaosrivathana & Ngaosrivathana, 2009; Fig. 1).

Rivers were the life blood of the migrating Tai, providing water for wet rice irrigation, a principal source of protein, and means of transportation. The direction of flow of the river was thus more important for them than the cardinal directions. Settlements were built along river banks, with the roof beams of all houses parallel to the direction of flow (Clément-Charpentier & Clément, 1990). Upstream took precedence over downstream.

Tai social structure was patrilineal and hierarchical. Tai society comprised three social groups: an aristocratic ruling family clan, the commoner farmers who provided labor in return for protection, and any non-Tai who attached themselves to the settlement. Settlement patterns reflected these social divisions. The houses of the ruling clan were located upstream; Tai commoners were grouped downstream; and further downstream again non-Tai were permitted to build their houses and conduct trade.

Narrow river valleys provided limited land for rice cultivation. Younger sons of the ruling clan were therefore encouraged to lead a few retainers in search of new land, usually further downstream. On riverine plains, larger settlements developed, which became the centers of small principalities (*muang*). In this way, the Lao filtered down the fast-flowing tributaries of northern Laos until they reached the mighty Mekong River, the mother of waters. At the junction of the Nam Khan River and the Mekong, a larger plain set within an amphitheater of hills provided resources for a more extensive polity. Here the Lao founded their royal capital (Stuart-Fox, 1998).

Luang Prabang, meaning city of the sacred Phra Bang Buddha image, was not originally so named. Not until centuries after the Lao had established their capital on this site did they convert to Theravada Buddhism. The city they built reflected Tai concepts of social order. The royal

City Planning of the Lao/Thai, Fig. 1 A protective *naga* and a river monster or *ngeuk*

City Planning of the Lao/Thai, Fig. 2 Xiang Thong temple, Luang Prabang

compound was located at the tip of the peninsula formed by the confluence of the Nam Khan and the Mekong. Downstream along the Mekong were the houses of minor aristocrats and court officials and beyond them the houses of commoners, mainly palace servants and artisans. Downstream again, beyond the city wall, were pottery kilns and lodging for the Mon traders who made their way up the Mekong, bringing with them their Buddhist beliefs (Fig. 2).

City Planning in Northern and Central Thailand

By the early thirteenth century, the middle reaches of the Mekong and Cao Phraya river systems had been incorporated into the Khmer empire, ruled from Angkor. Further north was the Mon kingdom of Haripunjaya, with its capital at Lamphun. Both employed Tai as mercenaries, but by the end of the century, the Tai population had increased to the point where their chieftains were able to seize power.

The cities they occupied embodied Khmer and Mon principles of city planning (see "► City Planning in Cambodia"). Khmer cities incorporated Hindu cosmological symbolism. They were square, with outer walls facing the four directions, each with a gateway in the middle leading to a central temple symbolizing Mount Meru, the *axis mundi*, in which usually the god Siva was worshipped. A separate gateway reserved for the king led directly to the royal palace, located just northwest of the temple mountain. Mon cities placed less emphasis on the four directions and more on the need for the king to demonstrate the great merit that for Buddhists legitimizes his power. The king's palace replaced Mount Meru at the city center, with royally endowed temples in close proximity.

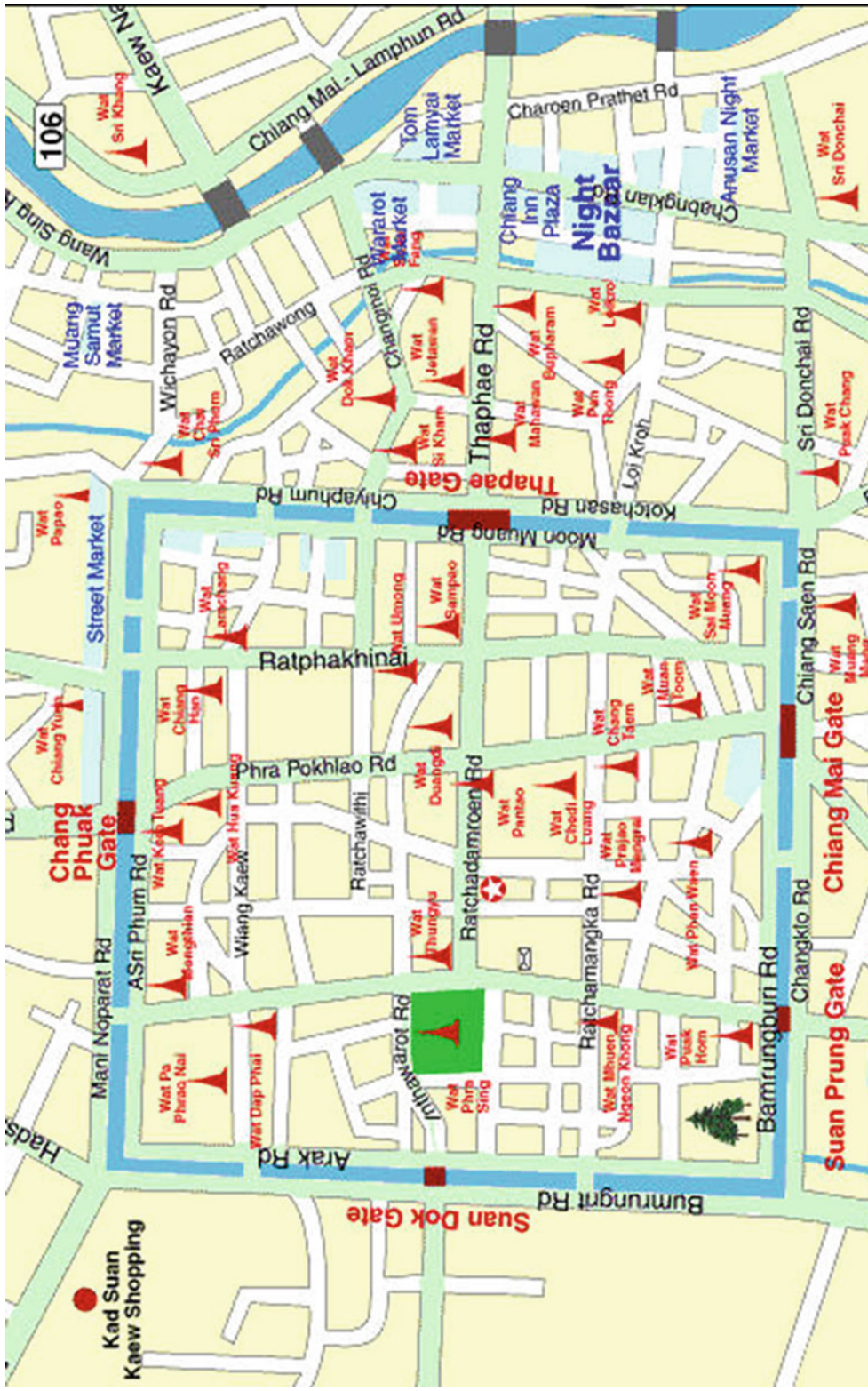
Through contact with the Mon to the south and Burmese to the west, the Tai *muang* of Laos and northern Thailand adopted Theravada Buddhism while retaining popular belief in *phi*. King Mangrai founded the Kingdom of Lanna ("a million rice fields") in 1262, with his capital at Chiang Rai, built in accordance with Tai planning principles on the south bank of the Nam Kok River. In 1296, however, Mangrai began construction of a new capital, Chiang Mai, meaning literally the "new city," on the Nam Ping River further south, which incorporated Mon/Khmer city planning (Wyatt & Wichienkeeo, 1995).

Chiang Mai was not built on the river, like Luang Prabang, but a short distance away from it with an outer wall and moat. The city was square, with sides 1.5 km long aligned with the four directions. The palace compound was located near the city center, with the principal royal monasteries close by. Walls to the east, north, and west were pierced by central gates that led directly to the palace, but the south wall had two gates, bringing the total to five, the same number as the great Khmer city of Angkor Thom. The fifth gate was not restricted to royalty, however, but rather gave access to the commercial area located, in accordance with Tai principles, outside the wall and downstream (Fig. 3).

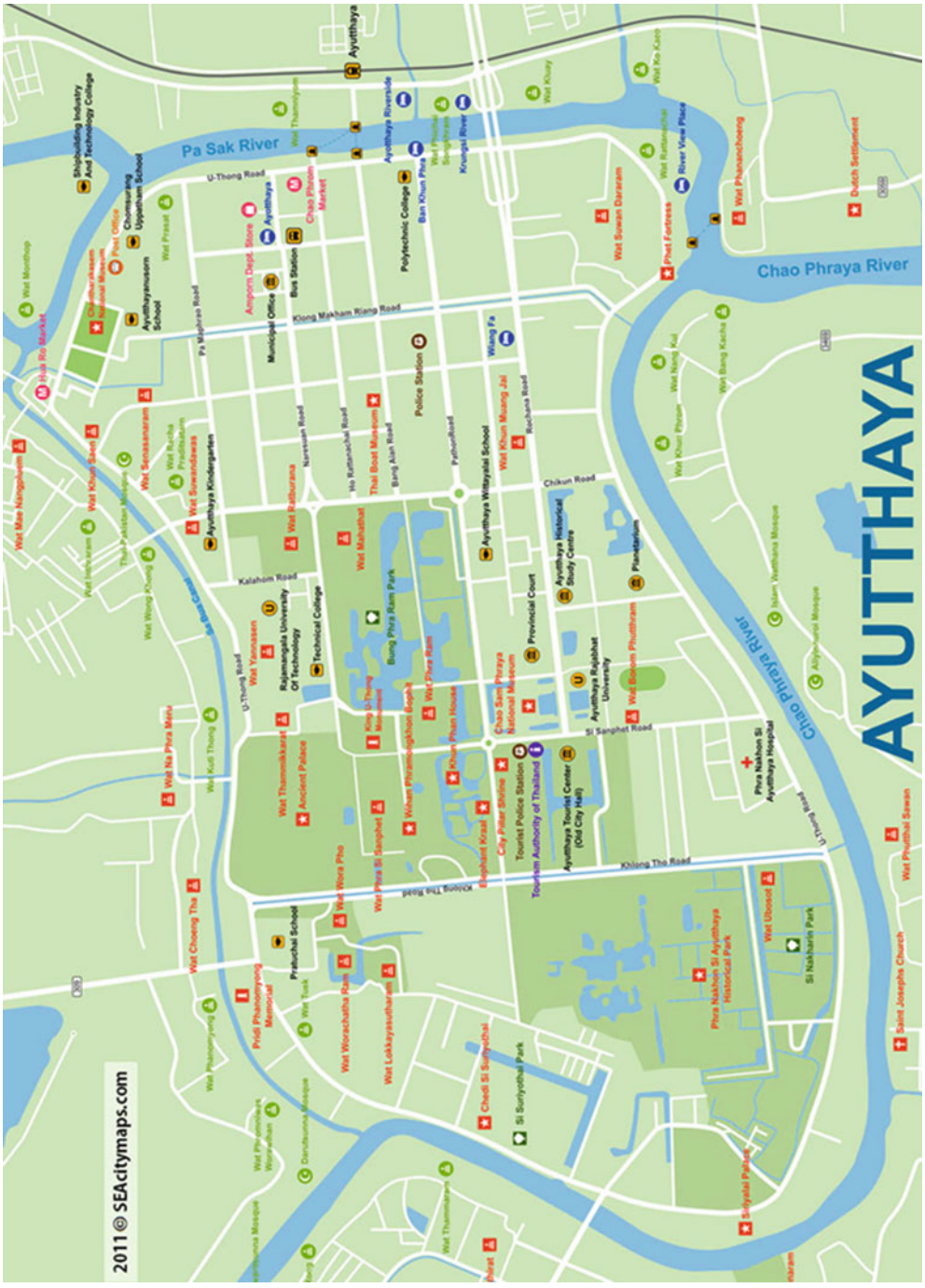
Chiang Mai was the first new city built by the northern Thai to combine borrowed Khmer principles of city planning with Mon Theravada Buddhist and traditional Tai concepts. Elsewhere in Thailand, Tai conquerors occupied existing Khmer provincial towns like Lopburi and Sukhothai. In later Thai capitals, the Khmer model still strongly evident in Chiang Mai was abandoned, leaving Theravada Buddhist and traditional Tai principles to dominate.

Ayutthaya was built on an island artificially created by joining up the Lopburi and Pasak rivers at their junction with the Chao Phraya. Though the palace compound has square outer walls, the city itself relied for protection on its river perimeter. The four directions played no part in the city plan. Nor was the royal palace at its center. In accordance with Tai planning principles, the palace was located near the bank of the most upstream part of the Chao Phraya River, surrounded by royal temples. The commercial areas where Chinese and European traders were allowed to take up residence were situated downstream (Garnier, 2004; Fig. 4).

When the Thai capital was moved to Bangkok early in the nineteenth century, the royal palace was again located close to the river and surrounded by royal temples, one of which, Wat Phra Kaeo, was constructed within the palace walls. The outer wall protecting the city was not square or rectangular, but roughly lozenge shaped, following the contours of the river to the west and moat to the east. In accordance with Tai planning principles, Chinese traders previously settled upstream of the palace were relocated downstream (Askew, 2002).



City Planning of the Lao/Thai, Fig. 3 Map of Chiang Mai showing the outline of the old city



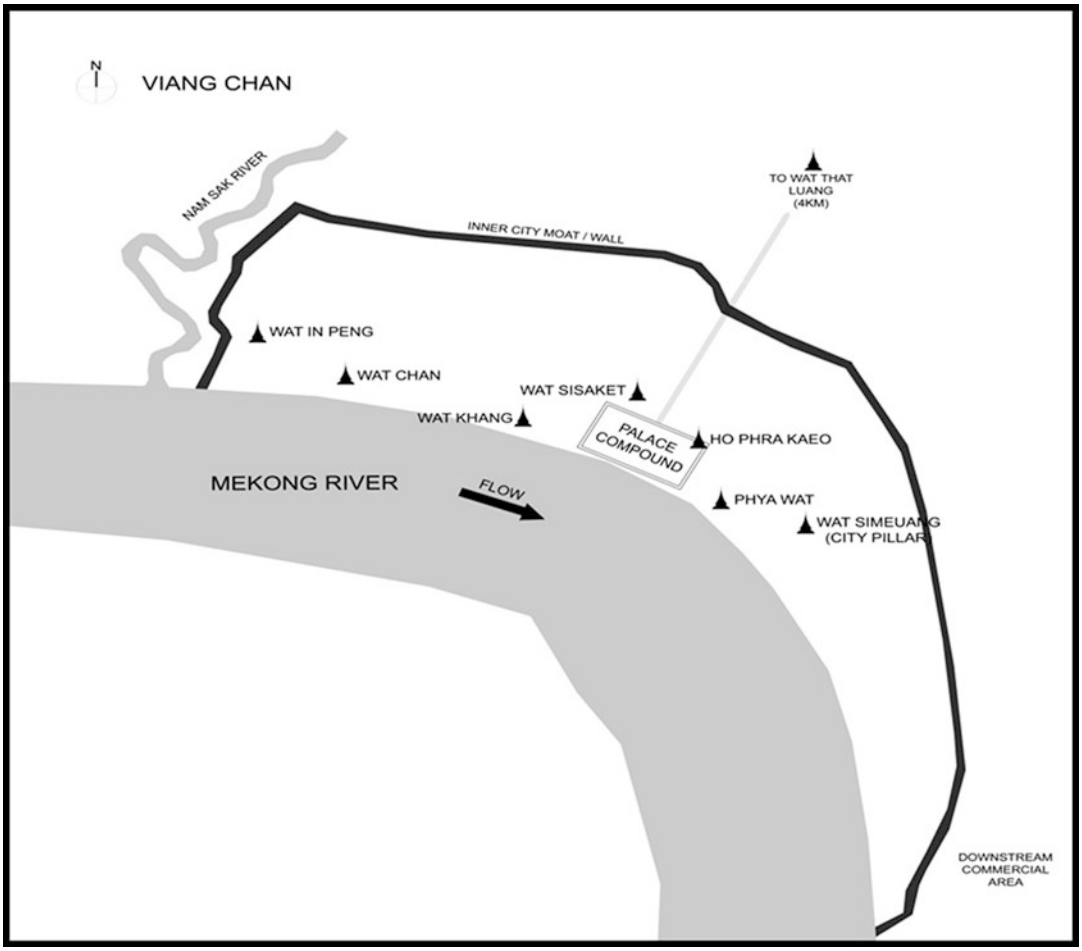
City Planning of the Lao/Thai, Fig. 4 Map of Ayutthaya

City Planning of the Lao/Thai, Fig. 5 Map of Luang Prabang

The Lao Variant

The original planning of Luang Prabang showed no Buddhist influence. The first Buddhist temples were constructed not near the palace but in the vicinity of Mount Phu Si, the small hill directly behind the old town, which missionary monks identified with Mt. Meru (Népote, 1997). Subsequently, royal temples were built in the vicinity of the palace to attest to the merit of the king. The symbolic significance of Mt Phu Si was recognized by capping it with a Buddhist stupa, but the palace remained where it was at the junction of the Nam Khan and the Mekong. All houses continued to be constructed with their ridge poles parallel to the flow of the closest river, whether the Nam Khan or the Mekong (Fig. 5).

When the Lao capital was moved to Viang Chan (Vientiane) in 1560, Buddhist cosmological principles took precedence over traditional Tai upstream–downstream relationships. The new royal palace was positioned not at the upstream extremity of the city but in relation to the revered That Luang stupa so that the line between them



City Planning of the Lao/Thai, Fig. 6 Sixteenth-century Viang Chan (Stuart-Fox & Reeve 2011)

was perpendicular to the flow of the river, which took precedence over the cardinal directions. The palace was bracketed, upstream and downstream, by royal temples, where the king could display his merit (Stuart-Fox & Reeve, 2011; Fig. 6).

The significance accorded to the That Luang in planning Viang Chan was reinforced by reconstruction of the stupa to symbolize Mt. Meru and its rededication as the Phra Chedi Lokachulamani, meaning "sacred reliquary stupa, precious jewel at the summit of the world." One of the grand gateways piercing the city wall, each large enough for an elephant to pass through, was located on the direct line between the palace and the stupa (Fig. 7).

In the early eighteenth century, the Lao Kingdom of Lan Xang (a million elephants) broke into three separate kingdoms: Luang Prabang in the north, Viang Chan, and Champasak in the south, each named after its capital city. Within 70 years, all three had been forced to accept the suzerainty of Bangkok. Luang Prabang, however, once again became a royal city, but with altered symbolic relationships that followed the model of Viang Chan. The new palace was constructed not where the original royal palace had been but further downstream in close proximity to the sacred hill of Mt Phu Si. Temples and the house compounds of aristocratic families were located upstream of the palace, while the commercial area remained well downstream.

City Planning of the Lao/Thai, Fig. 7 The That Luang stupa, Viang Chan

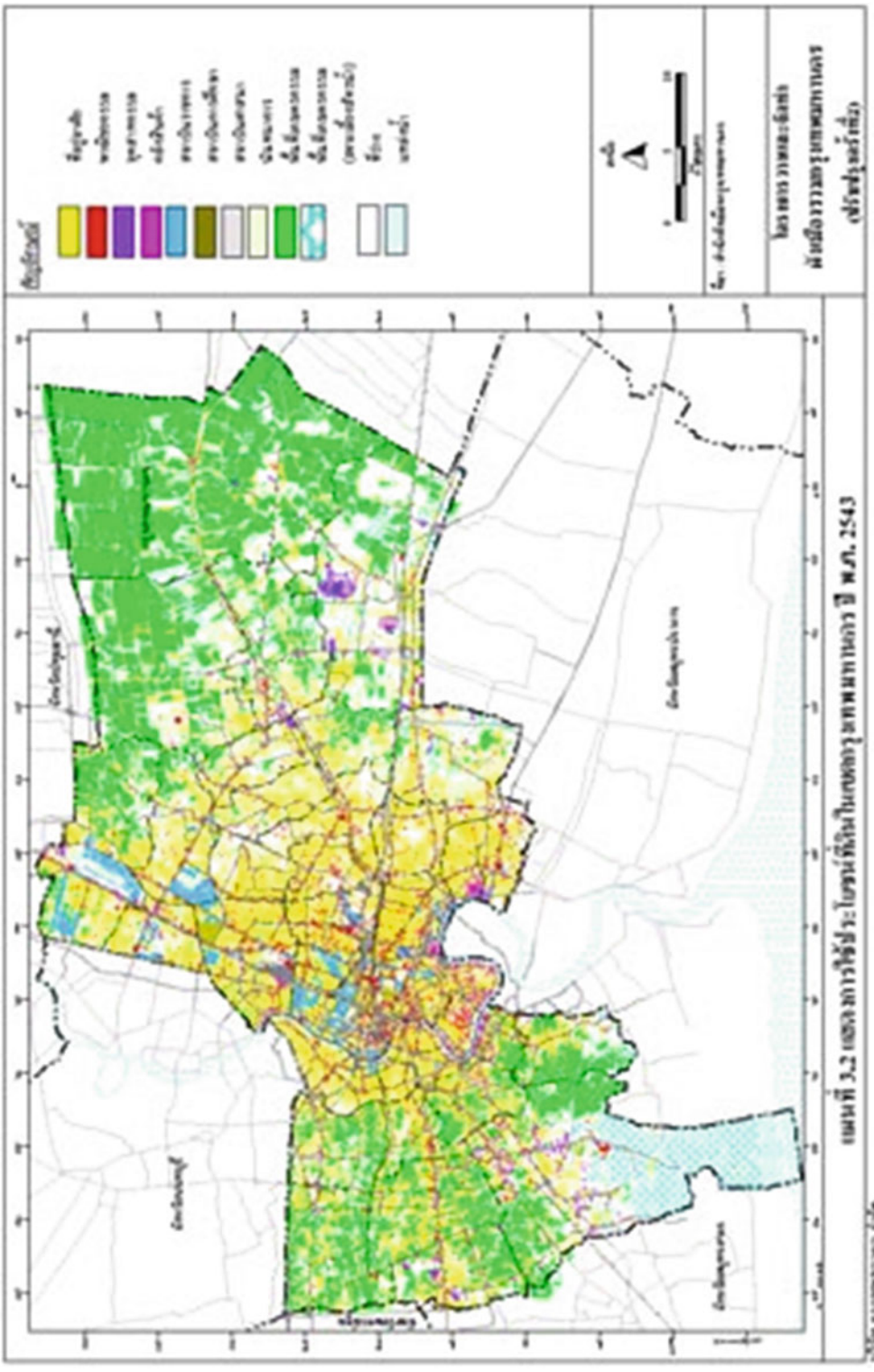
Modern City Planning in Thailand and Laos

Bangkok changed little during the first half of the nineteenth century, but under kings Rama IV and Rama V, commerce and industry began to develop. New canals were dug for drainage and arterial roads constructed to extend the city. Subsequently, many canals were covered over or filled in to create roads, as vehicles replaced boats for transportation and roads began to be paved. Trams were introduced and a railway terminus built for the new northern line. In 1932, the first bridge was constructed across the Chao Phraya to link Bangkok with Thonburi. As the city expanded upstream and downstream as well as east–west, all that remained of its original symbolic layout was the palace and royal temples.

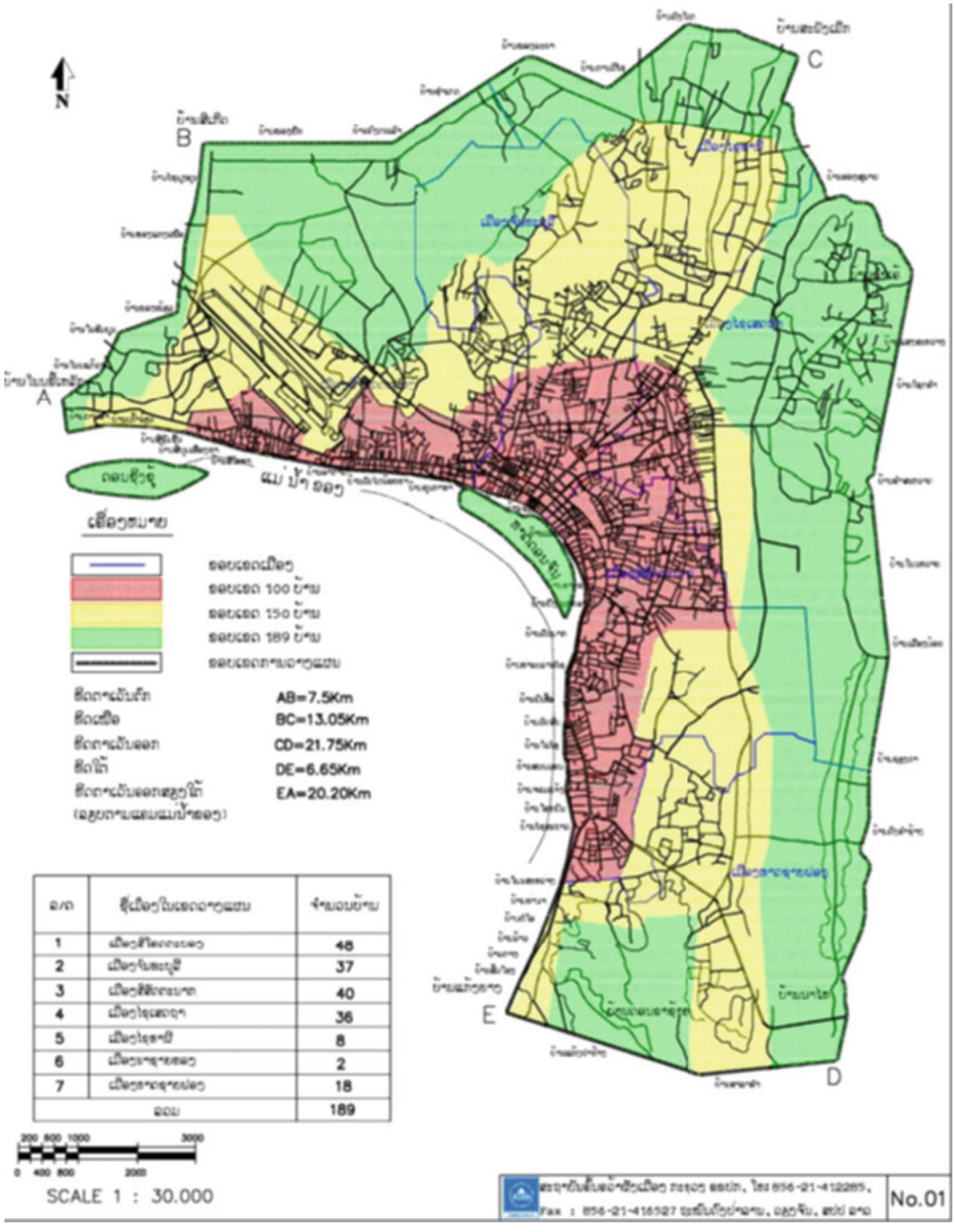
The expansion of Bangkok was largely unplanned, as nearby villages were incorporated into the urban sprawl. Though the population grew steadily, not until 1960 was the first comprehensive city plan drawn up (known as the Litchfield plan, after the American company entrusted with the task). The Greater Bangkok Plan 2533 (1990) envisaged a 30-year timeframe. It was essentially a land use plan (Sternstein, 1972), but was overtaken by increasingly rapid rural migration, which placed pressure not just on housing but also on transportation, distribution, and services. In 2006, the city's Planning Department drew up a new Comprehensive Plan for Bangkok-Thonburi, covering land use, transportation, and regulation, though implementation remained patchy (Fig. 8).

As Bangkok blossomed as the trading capital of the Siamese empire, Viang Chan languished. The city was completely destroyed during a Siamese invasion in 1827 to put down a Lao bid for independence, and its territories incorporated into the expanding Siamese empire. In 1893, however, France forced Siam to cede all Lao areas east of the Mekong. Six years later, it was decided to rebuild Viang Chan as the colonial capital of French Laos (Askew, Long, & Long, 2007).

The decision was powerfully symbolic: Laos was resurrected as a French protectorate, independent of Bangkok. The French began by mapping the earlier city within its ruined walls, taking care to preserve the grounds of the former royal temples. But this was no longer a royal city. The only remaining Lao king ruled in Luang Prabang. Viang Chan became the French administrative capital. To reinforce the fact that France was



City Planning of the Lao/Thai, Fig. 8 Comprehensive plan for Bangkok-Thonburi 2006



City Planning of the Lao/Thai, Fig. 9 Map showing planned expansion of Vientiane

now the ruling power, the mansion of the French governor was built precisely on the site of the former royal palace (Stuart-Fox, 2006).

The French planned Vientiane with care. A grid of roads ran perpendicular and parallel to the Quai Pavie along the Mekong, while, as in the old city, a main road ran at right angles to the Mekong from the Résidence compound to the That Luang (Clément-Charpentier, 2008). The city grew slowly by comparison to Bangkok, within the framework of a French Master Plan for the city prepared in 1962. Lao involvement in the Second Indochina War brought an influx of foreigners, but major expansion did not occur until Laos opened up to the outside world in the 1990s. Thereafter increased rural migration necessitated two further revisions of the 1985 Master Plan to envelop a total of 189 villages (Thammanosouth, n.d.). The growth of Vientiane has been less chaotic than in Bangkok; however, one controversial issue has been a large-scale Chinese housing development in the vicinity of the That Luang (Stuart-Fox, 2009; Fig. 9).

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City Planning: Aztec City Planning

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The Aztecs were the most urbanized of the ancient civilizations of Mesoamerica. The last in a long line of urban societies, they selected principles of city planning from an ancient Mesoamerican heritage and adapted these to their needs. Most Aztec urban centers were modest settlements best called towns, but the central capital Tenochtitlan was a huge metropolis of a different order.

Most Aztec towns were founded between AD 1100 and 1350 when the Aztec peoples immigrated into the central Mexican highlands. They established new settlements and dynasties leading to a system of autonomous city-states. The construction of a royal palace marked the official founding of a new city or town, most of them city-state capitals. In 1430, three Aztec peoples – the Mexica, Acolhua, and Tepanecs – formed a tributary empire, known as the Triple Alliance or the Aztec empire. Two of their capitals, Tenochtitlan (Mexica) and Texcoco (Acolhua),

City Planning: Aztec City Planning, Table 1 Historical sources of planning principles employed in Aztec cities

Principles of urban planning	Aztec towns	Tenochtitlan
Ancient Mesoamerican planning principles		
1. Inventory of public architecture	x	x
2. Urban epicenter	x	x
3. Central public plaza	x	
4. Astronomical orientations	x	x
5. Unplanned residential zones	x	
Teotihuacan innovations		
6. Huge size of the city		x
7. Massive scale of main temples		x
8. Orthogonal planning of entire city		x
9. Layout dominated by central avenue		
10. Lack of central public plaza		x
11. Standardized housing		x?
Tula innovations		
12. Formalization of the epicenter	x	x
13. The largest temple on the east side	x	x
14. Circular Quetzalcoatl temples	x	x
Aztec innovations		
15. Twin-temple pyramids	x	x
16. Multiple small altars	x	x
17. Walled ceremonial precinct		x

became the preeminent cities of the Valley of Mexico. By the time Spanish conquerors arrived in 1519, this empire had conquered much of Mesoamerica, and Tenochtitlan had grown into a city of 200,000.

One of the remarkable features of Aztec urban planning is the extent to which basic buildings and planning principles were standardized among cities throughout central Mexico. This standardization long preceded the formation and expansion of the Aztec empire, and its explanation probably lies in the common cultural origins of the Aztec peoples, coupled with processes of interaction that kept the rulers and nobility of the Aztec city-states in constant contact with one another. This uniformity in urban planning contrasts strongly with other Mesoamerican cultures, such as the Classic Maya, the Olmec, or the Zapotec, whose individual cities show far greater variation in architecture and urban layout.

Historical Development of Planning Principles

The Aztecs drew upon several ancient historical traditions to select principles of urban planning for their cities and towns. Not surprisingly, the two major Aztec urban types – city-state capitals and Tenochtitlan – had somewhat different historical legacies. In this section I outline 17 principles of urban planning employed in central Mexico, grouped into four historical categories based upon their historical origins: ancient Mesoamerican principles, Teotihuacan innovations, Tula innovations, and Aztec innovations. Table 1 lists these principles and their use in Aztec towns and in Tenochtitlan.

Ancient Mesoamerican Principles of Urban Planning

The Aztecs drew on ancient Mesoamerican principles of urban planning in the design of their

cities. Five such principles can be identified for the pre-Aztec cities of Mesoamerica, including those of the Classic Maya lowlands, Oaxaca, and other regions (for Mesoamerican architecture and cities, see Hardoy, 1968):

1. *The inventory of public architecture*. A basic set of public buildings were used in most ancient Mesoamerican urban centers: large temple pyramids, smaller temples, royal palaces, ballcourts, and a suite of less common special purpose buildings that included council halls, sweat baths, schools, and other structures.
2. *The urban epicenter*. Public architecture in Mesoamerican cities tended to be concentrated spatially in a central zone, called the urban epicenter. The locations and orientations of individual buildings often suggest coordination and planning, although strict formal patterns, such as orthogonal layouts, were rare.
3. *The central public plaza*. The basic unit of urban planning was the public plaza, an open rectangular space whose sides were taken up with public buildings. Large cities with multiple concentrations of public buildings often had multiple public plazas of different sizes.
4. *Astronomical orientations of buildings*. The ancient Mesoamerican peoples were accomplished astronomers, and key public buildings were often aligned with significant astronomical phenomena, such as the direction of sunrise on the solstice. There is a general tendency for urban epicenters to be aligned roughly to the cardinal directions (most typically several degrees east of north), a pattern that may also have derived from astronomical considerations (Aveni, 2001).
5. *Unplanned residential zones*. Most urban housing was located outside of the urban epicenter. Individual houses typically show little or no evidence that their locations, forms, or orientations were coordinated or planned by central authorities.

Teotihuacan Innovations

With a population of around 150,000 inhabitants, the huge metropolis Teotihuacan was the largest city in Mesoamerica (and one of the largest anywhere in the world) during the Classic period (ca. AD 150–650). Teotihuacan dominated central Mexico politically, and its economic and cultural influence extended to all corners of Mesoamerica. In its form and size, Teotihuacan was utterly unique in Mesoamerica, and only the later Aztec imperial capital Tenochtitlan can be said to resemble Teotihuacan at all (Cowgill, 1997; Millon, 1992). Six innovations in urban planning can be identified at Teotihuacan:

1. *The huge size of the city*. With an extent of over 20 km^2 and its huge population, Teotihuacan was a city of a different scale from anything seen previously in Mesoamerica (Fig. 1).
2. *Massive scale of the main temples*. Although not the tallest pyramids in ancient Mesoamerica, Teotihuacan's "Pyramid of the Sun" and "Pyramid of the Moon" are among the most massive in volume.
3. *Orthogonal planning of the entire city*. The principle of orthogonal city planning was quite rare in ancient Mesoamerica, found only at Teotihuacan, Tenochtitlan, and perhaps Tula. Teotihuacan is remarkable for the consistency of orientation of its buildings.
4. *Layout dominated by a central avenue*. The so-called Street of the Dead is a central avenue several km in length that forms the central axis for the layout of Teotihuacan (Fig. 1). This use of a dominant central avenue is not found elsewhere in Mesoamerica.
5. *Lack of a central public plaza*. There is a moderately sized open plaza at the north end of the Street of the Dead, but this plaza differs from typical Mesoamerican central public plazas in several key respects: it is small in relation to the size of the city; only a few of the central public buildings are adjacent to the plaza; and it is not centrally located within the city. Instead, the Street of the Dead

City Planning: Aztec City Planning, Fig. 1 The "Street of the Dead" at Teotihuacan (Photograph by Michael E. Smith)

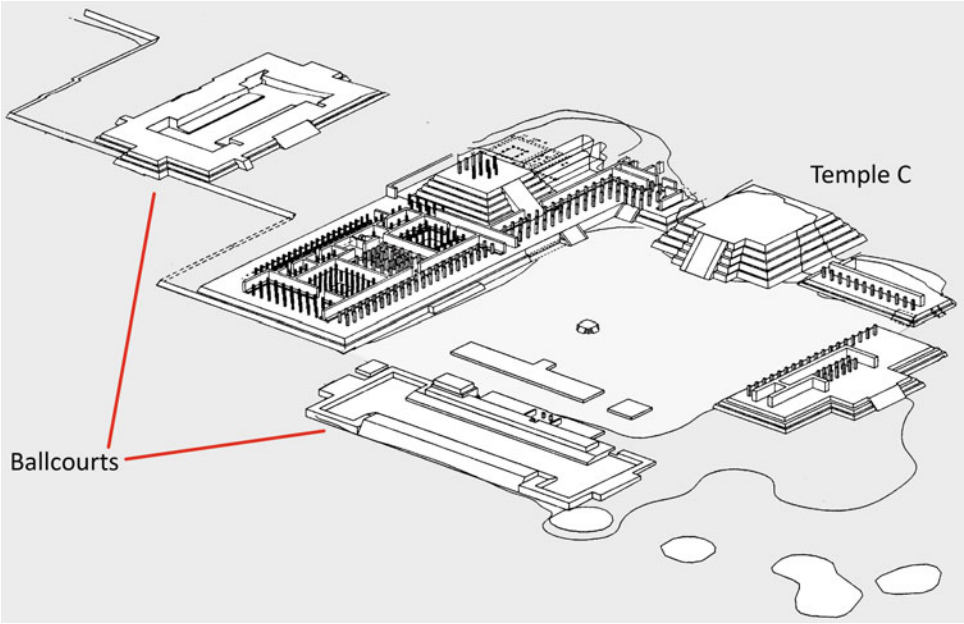
at Teotihuacan can be considered a functional analogue of the Mesoamerican central public plaza in terms of urban layout and planning. The major public buildings were arranged along this feature, which gave form to the entire plan of the city.

6. *Standardized housing*. One of the most remarkable urban features of Teotihuacan was the highly standardized form of commoner housing, the apartment compound. There were more than 2,000 apartment compounds in the city, all aligned to its orthogonal grid.

Tula Innovations

Tula, the next large political capital in central Mexico after Teotihuacan, drew on the layout of Teotihuacan for inspiration in urban planning. Although the rulers of Tula returned to the older Mesoamerican pattern of urban layout around a large public plaza, they employed several of the Teotihuacan innovations (nos. 6, 7, and perhaps 8). Although not as large as Teotihuacan, Tula was much larger than its central Mexican contemporaries and one of the largest cities in Mesoamerica during the Epiclassic and Early Postclassic periods, ca. AD 800–1200 (Mastache, Cobean, & Healan, 2002). Three urban planning innovations can be identified for Tula:

1. *Formalization of the epicenter*. The public plaza at Tula established an orientation that was used for all of the buildings in the urban epicenter (Fig. 2). This shows a higher level of coordination and formalization than was typical of other Mesoamerican urban epicenters. The Aztecs later adopted this principle for their urban epicenters.
2. *The largest temple on the east side of the plaza*. At Tula, the largest pyramid, Temple C, is located on the east side of the central public plaza, a pattern also used by the Aztecs.
3. *Circular Quetzalcoatl temples*. The cult of Quetzalcoatl, the feathered serpent, spread throughout Mesoamerica in the Epiclassic and Early Postclassic periods. In Postclassic times, circular temples were dedicated to Quetzalcoatl's avatar, the wind god Ehecatl



City Planning: Aztec City Planning, Fig. 2 Reconstruction of the epicenter of Tula (Modified after Mastache et al., (2002, p. 90))

(Pollock, 1936). At Tula, a circular temple was built at the El Corral locality, a concentration of public architecture outside of the main urban epicenter.

Aztec Innovations

The rulers of Aztec city-states drew primarily upon general Mesoamerican planning principles and Toltec innovations when they laid out their towns. The rulers of Tenochtitlan, on the other hand, emphasized these principles to a lesser extent, preferring planning principles from Teotihuacan. Three innovations can be identified for Aztec cities:

1. *Twin-temple pyramids*. Several of the earliest Aztec cities (e.g., Tenayuca and Teopanzolco) used a new form of pyramid with two temples on top and two stairways (Fig. 3). By the Late Aztec period, this form had fallen out of fashion except at the central temples of Tenochtitlan and Tlatelolco.
2. *Multiple small altars*. One of the notable attributes of Aztec cities is the prevalence of small platforms or altars throughout the urban epicenter (Fig. 4). These were often located within the public plazas, and some altars were adjacent to large pyramids.
3. *Walled ceremonial precinct*. The central religious architecture at Tenochtitlan was concentrated within a walled compound called the "sacred precinct." Although some authors have suggested that this was a regular feature of Aztec cities, Tenochtitlan is in fact the only example with a well-documented walled precinct.

These 17 principles are listed in Table 1.

Urban Architecture

In addition to their use of ancient Mesoamerican traditions of urban planning, the Aztecs also made use of Mesoamerican patterns of monumental architecture. The basic religious structures were temple pyramids, typically rebuilt and expanded by successive kings. When archaeologists excavate into a Mesoamerican pyramid, they typically find the buried remains of one or

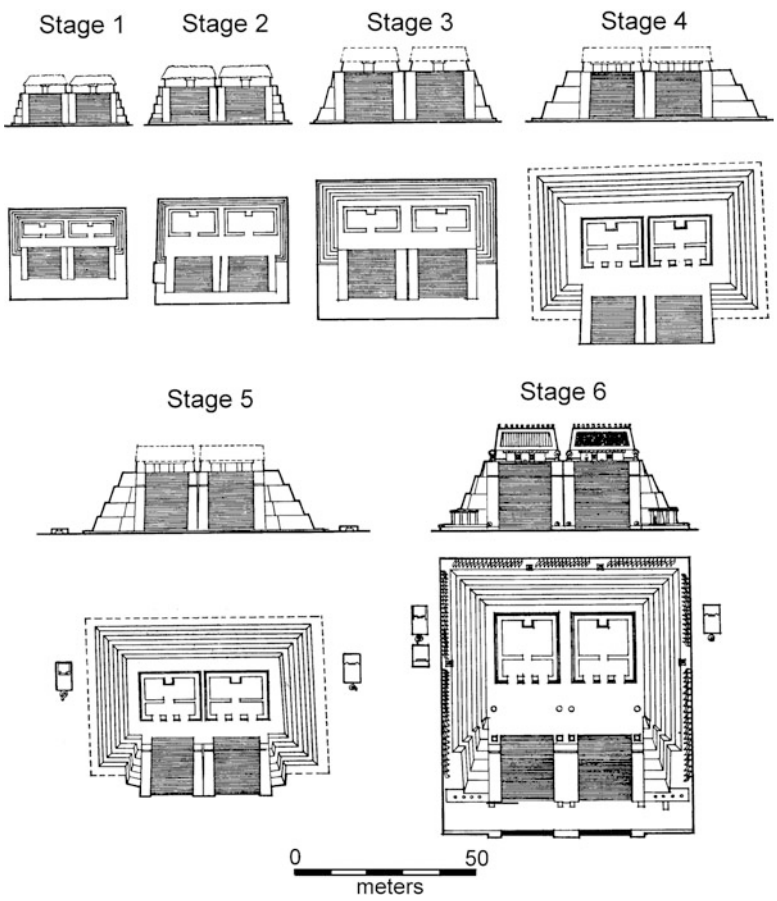
City Planning: Aztec City Planning, Fig. 3 Aztec twin-temple pyramid at Teopanzolco (Photograph by Michael E. Smith)

City Planning: Aztec City Planning, Fig. 4 Row of small altars at Teopanzolco (Photograph by Michael E. Smith)

more earlier construction stages (Fig. 5). This continual rebuilding of temples in the same location was related to notions of sacred space and the importance of continuity with the past. In addition to temple pyramids, the Aztecs also used the basic Mesoamerican architectural inventory of palaces, ballcourts, altars, and commoner houses.

Twin-Temple Pyramids

This innovative form of temple pyramid is found at only five Aztec cities. Two of the major political capitals of the Early Aztec period – Tenayuca and Teopanzolco – employed large twin-temple pyramids for their central state temples (Fig. 3). Excavation of the Tenayuca pyramid revealed



City Planning: Aztec City Planning,
Fig. 5 Construction stages of the twin-temple pyramid at Tenayuca (From Smith (2003a, Fig. 2.8); based upon (Marquina, 1951, p. 169))

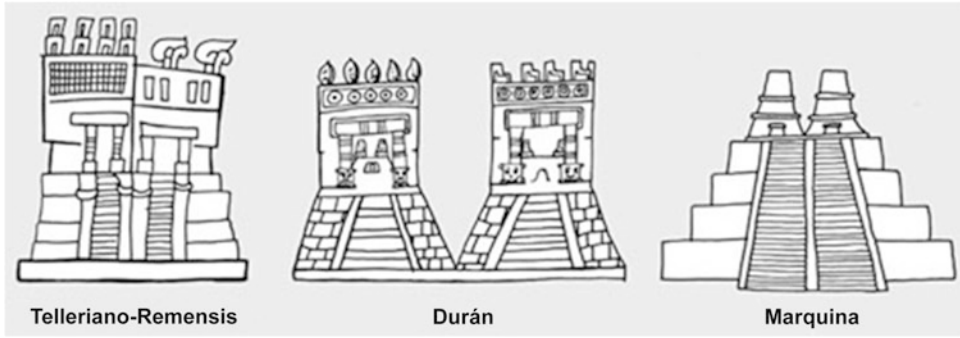
a series of enlargements and expansions (Fig. 5), all employing the double temple design. By the Late Aztec period, this style had fallen out of fashion at most Aztec cities, whose main pyramids had only a single temple. But the Mexica peoples at the twin cities of Tenochtitlan and Tlatelolco revived this form for their central pyramids. At the well-known Templo Mayor of Tenochtitlan, the temples were dedicated to Tlaloc (an ancient central Mexican fertility god) and Huitzilopochtli (patron god of the Mexica with associations of warfare and sacrifice). This structure is known both from excavations (Matos Moctezuma, 1988) and from pictorial sources (Fig. 6).

Single-Temple Pyramids

The single-temple pyramid was the standard form of temple throughout most of Mesoamerican history. The extent of its use during the Early Aztec period is hard to judge, but by Late Aztec times, this form dominated Aztec cities, serving as both their central temples and as subsidiary temples (Fig. 7).

Circular Pyramids

Many Aztec cities and towns had circular pyramids dedicated to the wind god, Ehecatl (Fig. 8). These temples were rarely if ever located in central positions in Aztec cities. In some cases (e.g., Tlatelolco and Tenochtitlan), these temples were located within the urban epicenter but somewhat apart from the central twin-temple pyramid (Guilliem Arroyo, 1999). In other cases (e.g., Huexotla, Zultepec, and perhaps Calixtlahuaca), the circular temples were located far from the urban epicenter, as at the earlier city of Tula.



City Planning: Aztec City Planning, Fig. 6 Native drawings of the Templo Mayor of Tenochtitlan (From Smith (2003b))

City Planning: Aztec City Planning, Fig. 7 Small single-temple pyramid at Calixtlahuaca (Photograph by Michael E. Smith)

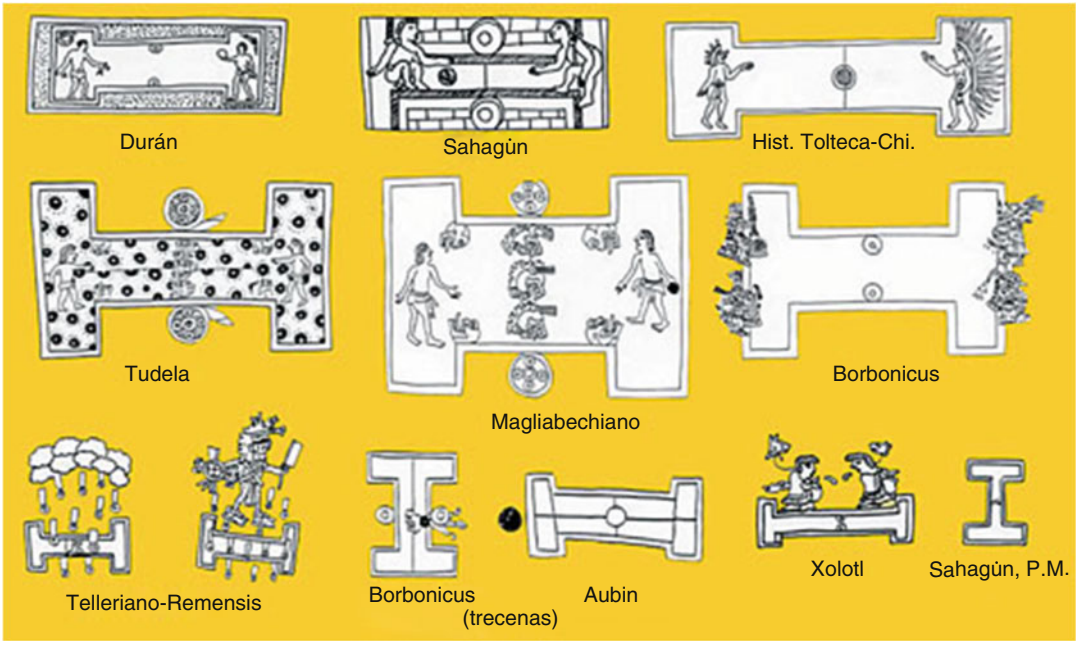
Ballcourts

Only a few Aztec ballcourts have been located, but given the prominence of ballcourts and the ballgame in Aztec codices (Nicholson & Quiñones Keber, 1991) (Fig. 9), it is likely that these features were integral parts of most city layouts. The restored ballcourt at Coatetelco (Fig. 10) is probably typical of Aztec ballcourts; see also Matos Moctezuma (2001). The Aztecs played a version of the Mesoamerican ballgame, a public performance using a rubber ball that combined sport, ritual, and politics in poorly understood ways.

Palaces

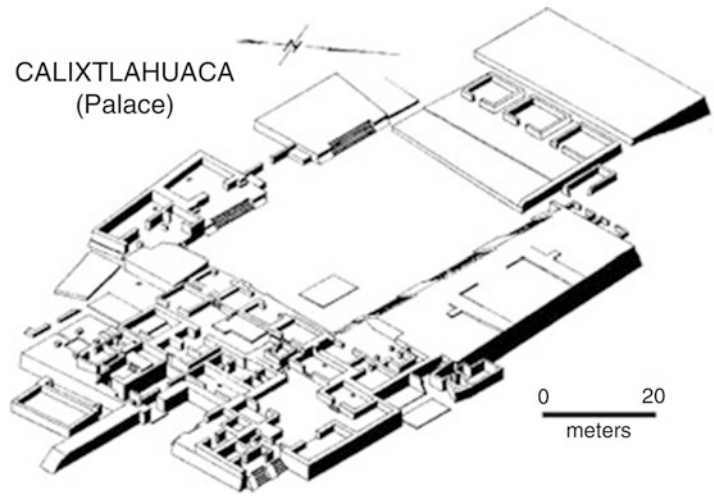
Aztec palaces, unlike those of the Classic Maya, were highly standardized in layout. They contained a central courtyard with a single entrance. The courtyard was enclosed by raised platforms, on top of which were arranged a series of rooms, halls, altars, and other features (Figs. 11 and 12). This standard plan was followed for

City Planning: Aztec City Planning, Fig. 8 Circular temple at Tlatelolco (Photograph by Michael E. Smith)



City Planning: Aztec City Planning, Fig. 9 Depictions of ballcourts in the Aztec codices (Modified after Nicholson & Quiñones Keber (1991))

City Planning: Aztec City Planning, Fig. 10 Ballcourt at Coatetelco (Photograph by Michael E. Smith)



City Planning: Aztec City Planning, Fig. 11 Reconstruction of the palace at Calixtlahuaca (Modified after Smith (2003a, Fig. 8.7); based originally upon (García Payón, 1981, Fig. 8))

a whole range of palaces, from the sumptuous royal palaces of Tenochtitlan and Texcoco to the modest residences of provincial nobles (Evans, 1991; Smith, 2003a).

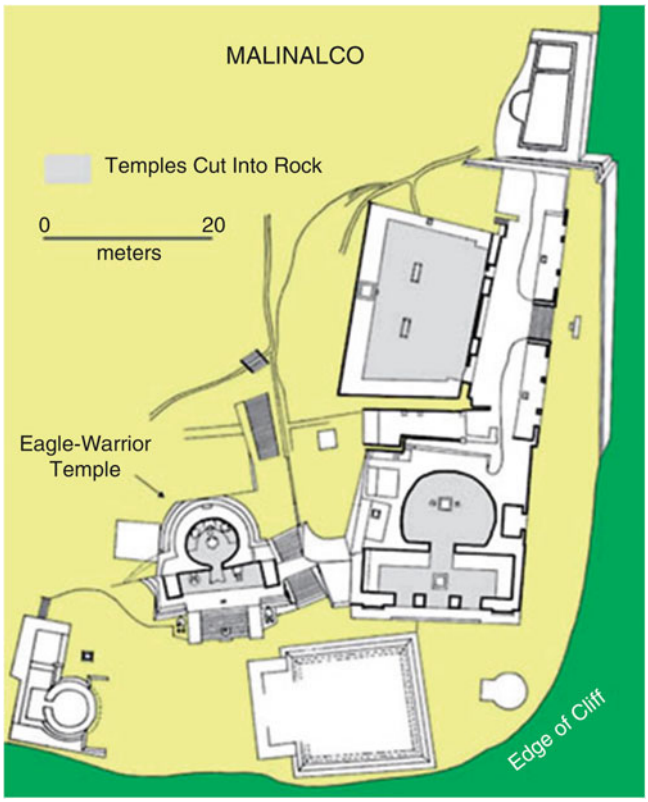
Special Purpose Buildings

A variety of specialized buildings are known from archaeology and documentary sources. Written sources mention two types of schools, but none have been excavated. Special buildings for elite warriors have been excavated adjacent to the Templo Mayor of Tenochtitlan and in a rock-cut chamber at the hilltop ceremonial precinct of Malinalco (Fig. 13).

Altars and Small Platforms

Among the more intriguing and poorly understood features of Aztec cities are small altars

City Planning: Aztec City Planning, Fig. 12 Rooms in the royal palace of Yautepec (Photograph by Michael E. Smith)



City Planning: Aztec City Planning, Fig. 13 Map of the hilltop ceremonial zone of Malinalco (From Smith (2003a, Fig. 7.5); based originally upon Marquina (1951))

City Planning: Aztec City Planning, Fig. 14 Altar decorated with carvings of human skulls at Tenayuca used to worship the *tzitzimime* deities (Photograph by Michael E. Smith)

and platforms that typically occur in multiple groups (Fig. 4). There were evidently numerous categories of such altars, dedicated to diverse deities and with a variety of uses in ritual and performance. Two specific functional types have been identified so far: platforms that supported skull racks (for the display of the skulls of sacrificial victims) and altars dedicated to the curing principles of the *tzitzimime* deities (Fig. 14) (Klein, 2000). The Aztecs even journeyed to Tula to build a small altar in front of Temple C, perhaps symbolically to convert the ancient structure into an Aztec temple.

Commoner Housing

Two patterns of commoner housing have been identified at Aztec cities. At Tenochtitlan and other cities in the Valley of Mexico, house compounds enclosed by low walls was the norm (Calnek, 1974; Evans, 1988). These compounds contained a number of structures and rooms arranged around an open work area (Fig. 15). In the provinces, in contrast, commoners lived in individual adobe houses (Smith, Heath-Smith, Lisa, & Montiel, 1999). Although often arranged into groups around a central patio, these house groups were never enclosed with walls (Fig. 16). Commoner housing exhibited considerably more variation within and between cities than was found in the palaces of the nobility.

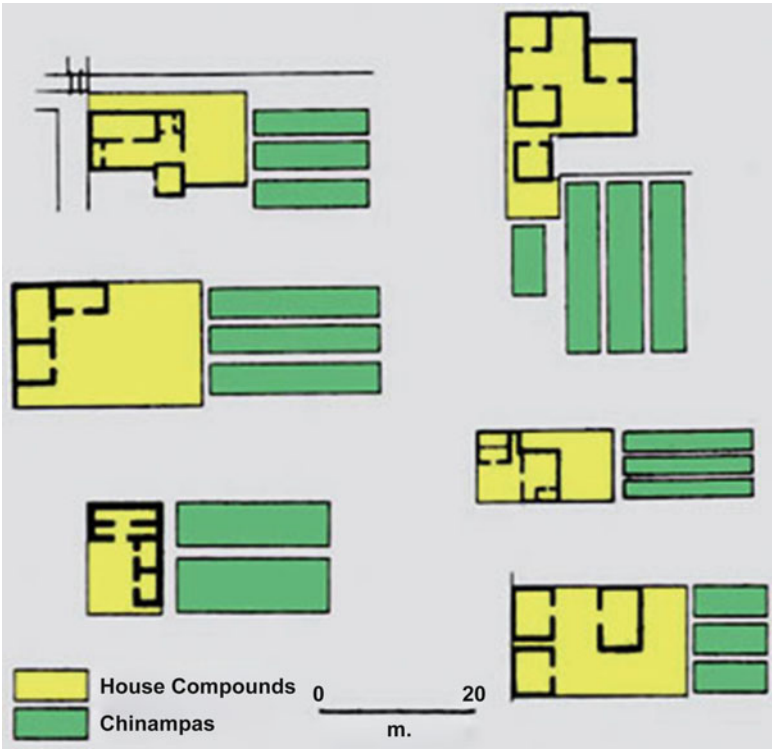
Categories of City

City-State Capitals

As noted above, the designers of Aztec cities and towns drew upon the principle of the formalized urban epicenter as articulated at the ancient city of Tula (Fig. 17). The city of Coatetelco in Morelos (Arana Alvarez, 1984) illustrates this pattern (Fig. 18). The central pyramid lies on the east side of the plaza (as at Tula), with the ballcourt opposite. Five small altars or platforms, attached to the exterior wall of the ballcourt, extend into the plaza. The buildings on the north and south sides of the plaza were only partially excavated and their functions are not known. The formal, planned central plazas of Aztec towns are clear even in the overgrown mounds at unexcavated urban sites such as Coatlan Viejo (Fig. 19). Although it is possible that the planned layout of the epicenters and their consistent orientations just east of north are related to cosmological principles, there is no concrete evidence to support this interpretation.

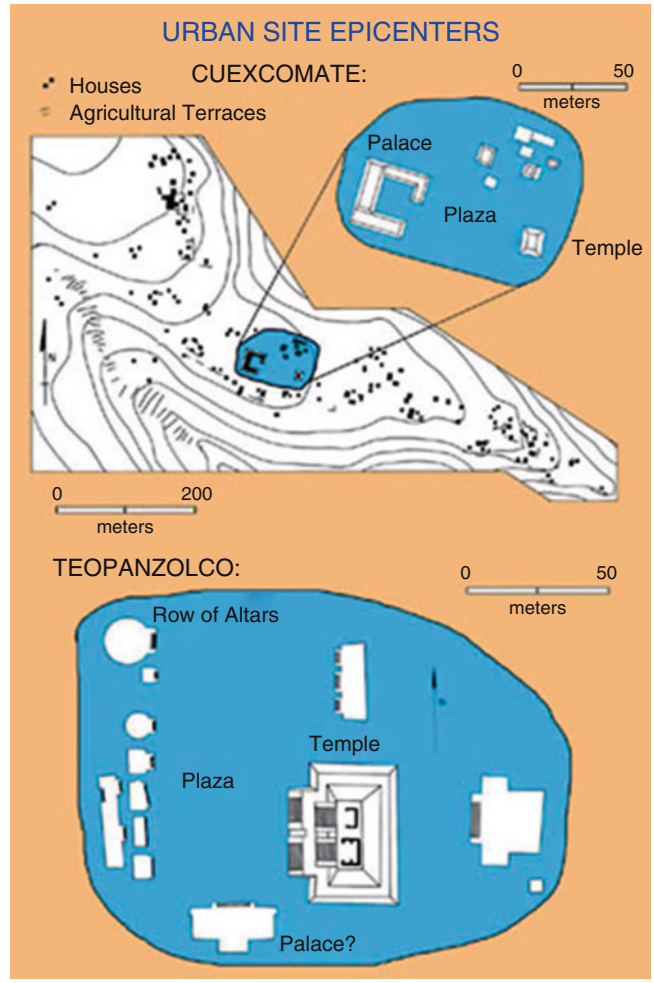
Outside of the epicenter, the residential zones of Aztec towns exhibited little evidence for planning or coordination. Although only one Aztec town – Cuexcomate – has been mapped in its entirely (Fig. 17, top), residential excavations in other cities and towns are consistent with this interpretation of unplanned residential areas (Smith et al., 1999).

A related type of settlement was the hilltop ceremonial zone, found in a number of Aztec

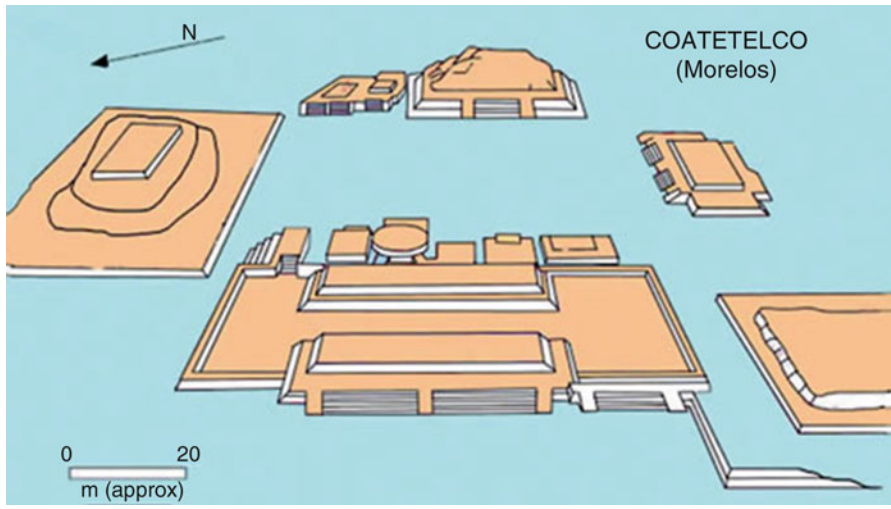


City Planning: Aztec City Planning, Fig. 15 Commoner houses with *chinampa* (agricultural) fields (Modified after Calnek (1972, p. 112))

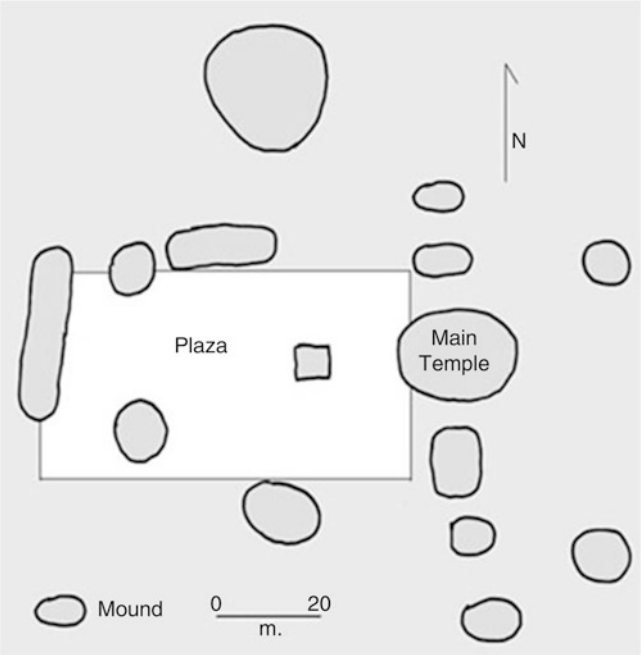
City Planning: Aztec City Planning, Fig. 16 Commoner houses excavated by the author at Yautepec (Photograph by Michael E. Smith)



City Planning: Aztec City Planning, Fig. 17 Definitions of urban epicenters of Cuexcomate and Teopanzolco (Modified after Smith (2005, Fig. 2))



City Planning: Aztec City Planning, Fig. 18 Reconstruction of the plaza at Coatetelco (Modified after Smith (2003a, Fig. 8.2); based originally upon Konieczna (1992))



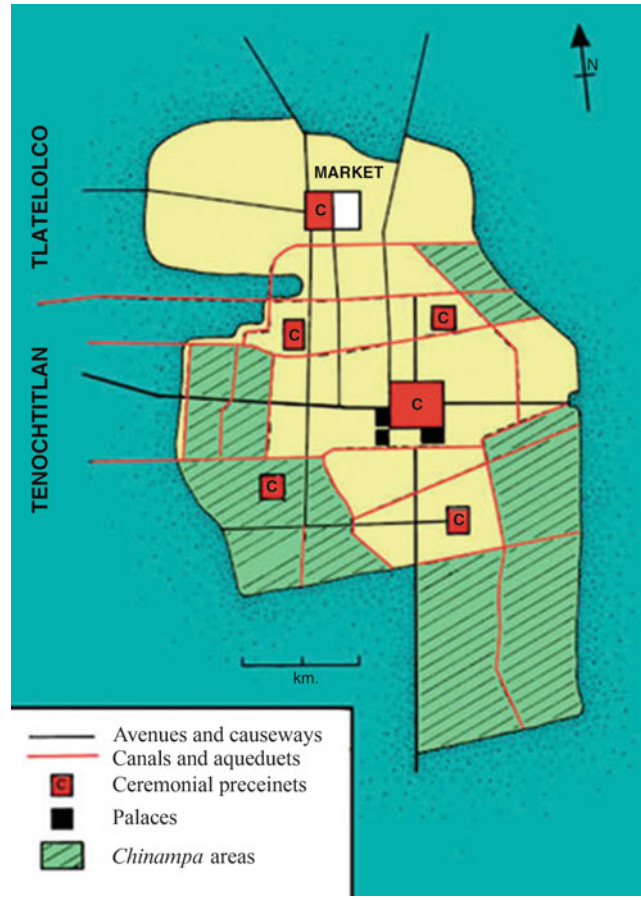
City Planning: Aztec City Planning, Fig. 19 Map of the epicenter of Coatlan Viejo, an unexcavated city-state capital in Morelos (Modified after Mason (1980, p. 53))

city-states. The rituals carried out at these locations were typically political ceremonies linked to both agricultural fertility and the religious legitimation of kings and dynasties. The best known examples are Cerro Tlaloc in the Valley of Mexico, Malinalco in the State of Mexico (Fig. 13), and Tepozteco in Morelos.

Tenochtitlan

When the Mexica peoples constructed Tenochtitlan on an island in Lake Texcoco in the early fourteenth century (the official date for the founding of the city is AD 1325), they drew more inspiration from Teotihuacan and Tula than from the standard Aztec urban plan already established at many towns in central Mexico (Table 1). The use of orthogonal planning is one of the remarkable features of the imperial capital (Fig. 20). Although few explicit articulations of urban planning concepts have survived, three factors were most likely responsible for creating the form of Tenochtitlan: the city's island location, imperial ideology, and cosmological principles. Most of Tenochtitlan's 13.5 km^2 were reclaimed from Lake Texcoco. Spanish observers were struck by the great number of canals in the city, which they likened to Venice. The canals were used as transportation arteries and for agricultural purposes. Raised fields or *chinampas*, an extremely productive method of farming, were built to cultivate reclaimed swampy land in the outer neighborhoods of the city (Calnek, 1972). Families living on their individual small plots worked these fields (Fig. 15). As the city expanded, many of these rectilinear chinampas were converted into dry land, contributing to the orthogonal plan of the city.

Tenochtitlan's orthogonal layout is seen in the major avenues radiating out from a central ceremonial precinct in the cardinal directions (Fig. 20). The avenues divided Tenochtitlan into four quarters, each with its own smaller ceremonial precinct. Outside of the chinampa areas, houses were packed tightly together. The city of Tlatelolco, with its own impressive epicenter (Fig. 8), was originally a separate town but was later incorporated into Tenochtitlan (González



City Planning: Aztec City Planning, Fig. 20 Map of Tenochtitlan (From Smith (2003a, Fig. 8.8); based originally upon (Calnek, 1972, p. 108))

Rul, 1998). By drawing on the orthogonal layout of Teotihuacan (Fig. 1), the Mexican rulers proclaimed Tenochtitlan's continuity with the past and its legitimacy as the imperial capital of central Mexico (Umberger, 1987).

Cosmological principles also contributed to the form and layout of the capital. The largest structure, the Templo Mayor (Fig. 6), was viewed as the symbolic center of the Aztec empire (Carrasco, 1999; López Luján, 1994), and it was the setting for elaborate state ceremonies including human sacrifices. The Templo Mayor was built in alignment with sunrise on a key holy day (Aveni, 2001), and the entire layout of Tenochtitlan can be viewed as an extension of the sacred orientation of the central temple.

In sum, the planners who laid out Tenochtitlan made radical breaks with past Aztec (and Mesoamerican) norms in two ways. First, they filled the central plaza with buildings. In place of an open plaza is the sacred precinct, a large walled compound packed with temple pyramids, altars, priests' residences, and other sacred buildings (Fig. 21). The palaces of the Mexica kings were arranged around the outer walls of the precinct. The sacred precinct occupies the place of the public plaza in other Aztec (and Mesoamerican) cities. Second, the imposition of a common grid over the entire city was a radical practice that expressed the power of the rulers to shape their city and differentiate it from other Aztec cities. The orthogonal layout also exemplified continuity with Teotihuacan and resonated with ancient Mesoamerican cosmological principles of the importance of the cardinal directions.

City Planning: Aztec City Planning, Fig. 21 The walled "Sacred Precinct" at Tenochtitlan (After Marquina (1951, lámina 55))

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City Planning: Inca City Planning

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Although the Incas were not great city builders, they redesigned their capital, Cuzco, on a grand scale, and founded numerous new settlements. Ollantaytambo is one such new town. Because it has what "may be the oldest continuously occupied dwellings in South America" (Kubler, 1975), and because many parts of the town are well preserved, it would seem the perfect object for the study of the town planning principles of the Incas.

Ollantaytambo is located about 90 km to the northwest of Cuzco at the confluence of the Urubamba and the Patakancha rivers. It is built on a narrow, gently sloping bench of artificially leveled ground squeezed in between Cerro Pinkuylluna to the east and the Patakancha river to the west. It is carefully sited so as not to occupy prime agricultural land, yet to provide easy access to the terraced fields to the north and the south. The glacier-fed Patakancha provides an ample water supply for both agricultural and domestic uses. Tucked in between the high mountains at the mouth of the Patakancha valley, the town is well protected from the fierce afternoon winds which often sweep through the broader Urubamba valley.

The town was laid out on a regular grid, trapezoidal in shape, of four longitudinal and seven transversal streets. The transverse streets, oriented at 110.5° east of magnetic north, are perfectly parallel to each other, suggesting that the Inca were knowledgeable about geometry, and that they had a method of surveying to lay out the streets.

In the time of the Incas, there was a large plaza in the middle of the town. On its north and south sides it was bordered by great halls, long buildings with many openings toward the plaza. If what Garcilaso de la Vega tells us about Cuzco holds for Ollantaytambo, then the plaza was the theater for ceremonies and festivities, and the great halls were the place where the revelers withdrew to pursue their activities on rainy days (Garcilaso de la Vega lib. VII, cap. X; 1976: II, 108).

The fifth transverse street manifestly divided Ollantaytambo into two parts with distinct architectural features: the street facing walls in the southern half of town were built of cut and fitted stones, whereas in the northern half they were

built of unworked field stones. The blocks in the southern half show a rigorously repetitive block design of two walled-in habitation compounds, called *kancha*, arranged back to back, that is not reflected in the northern half. Cobo stated:

> The Incas imposed in all their kingdom the same division in which the city of Cuzco was divided, Hanan Cuzco and Hurin Cuzco; cutting each town and lordship into two parts or factions called hanansaya and hurinsaya, which means "the upper district" and "the lower district," or the part or faction from above and the faction from below;... (Cobo lib. XII, cap. XXIV; 1964: II, 112).

This division, which is a social one and probably has ancient Andean roots, was used by the Incas to control, administer, and inspire their subjects (Cobo lib. XII, cap. XXIV; 1964). The two moieties were essentially equal, and each was governed by its own leader, with the *hanan* leader having first rank. It is possible, but not demonstrated, that the architectural division observed at Ollantaytambo is a referent to this social division.

Because of the rigor and clarity with which the town of Ollantaytambo has been laid out, one might be tempted to interpret it as an exemplar of Inca town planning. A comparison from a formal point of view with other Inca sites, however, does not sustain this proposition. Outside Ollantaytambo regular grids are only found at Chucuito, on Lake Titicaca, and Calca. The Chucuito grid too is trapezoidal in shape, and that of Calca appears to be strictly orthogonal. It is not known with certainty whether the Chucuito grid is of Inca origin. Calca, on the other hand, is known to have been established by Waskhar, the twelfth Inca. Whether or not the blocks in these two sites were occupied by kancha is not known. Cuzco, the navel of the Inca empire, shows an ordered street pattern, but the grid and the block sizes are not as regular and uniform as those of Ollantaytambo. At least some blocks in Cuzco were built up with compounds very similar to the kancha at Ollantaytambo. Huánuco Pampa, a large administrative center in the central highlands, lacks a regular street pattern, and although there are discernible town blocks, they are quite irregular in size and shape. Many kancha-like compounds are scattered throughout the site, but their design is quite varied and irregular, and the compounds do not define blocks or streets. At Patallaqta, some 20 km downstream from Ollantaytambo, the kancha design is prominently in view. There are two arrangements of kancha; one consists of two kancha, back to back, similar to Ollantaytambo, except that it is not walled in; the other is made of four smaller kancha. Even though the kancha are not walled in, their groupings nevertheless define town blocks and streets. Tambo Colorado, an administrative center in the coastal valley of Pisco, has neatly rectangular compounds, but the center is not built on a grid pattern of streets, and the compounds only remotely recall the kancha design. The only feature common to the sites discussed above appears to be a plaza. At Huánuco Pampa the plaza is huge; it measures about 540×370 m^2, is surrounded by buildings on all sides, and is dominated by what must be the largest remaining *usnu*, a ceremonial platform. Two great halls face the plaza on its east side. The plaza, *Hawkaypata*, in Cuzco was also quite large, about 200×250 m^2. It too had an usnu, and was bordered with great halls on its north and east sides. Tambo Colorado's trapezoidal plaza is surrounded by buildings on three sides and has an usnu on its fourth side, but no great halls face it. Whether the plaza at Ollantaytambo had an usnu is not established. Thus, if the plaza is a recurrent element of Inca settlements, its configuration is by no means standard.

If no specific town planning rules seem to emerge from the comparison of different Inca settlements with Ollantaytambo, it stands to reason that Ollantaytambo is not representative of Inca town planning. It has been said that the Incas laid out their new settlement in the image of their capital, Cuzco. However, a comparison of the various plans analyzed above does not fare much better; there are no more similarities between Cuzco and the other sites than there are between them and Ollantaytambo. Rowe suggested that Cuzco was laid out in the shape of a Puma. Neither of the plans reviewed can be made to fit this shape. Perhaps similarities between Cuzco and other sites should not be

searched for the physical form, but instead, as Gasparini and Margolies (1980) suggested, "in the meaning and the functions of the form." They argue that, if one makes abstraction of the physical form, one will note that certain elements are "repeated with considerable insistence." They list the division into *hanan* and *hurin*, a principal and a secondary plaza, the great halls on the plaza, the *usnu*, the *inkawasi* (house of the Inca), the *aqllawasi* (house of the Chosen Women), the temple of the sun, and the storehouses. In light of the difficulties of attributing specific functions to particular ruins, and the uncertainties regarding a physical referent for the division into *hanan* and *hurin* discussed above, the effort to establish similarities among settlement patterns, and to derive planning canons, is considerably weakened.

The Spanish chronicler Bernabe Cobo described an elaborate set of about 40 lines, called *zeq'e*, radiating out in all directions from the Qorikancha, the holiest of all Inca shrines, in Cuzco. Along each line were arranged a number of sacred places and objects. Each line was the responsibility of a specific royal family of Cuzco. The families were in charge of officiating at the shrines in their care and of providing the appropriate sacrifices on the designated days. Although Tom Zuidema (1964) argued that the zeq'e influenced the plan of Cuzco, and perhaps of other Inca settlements, it is obvious that the radiality of the zeq'e did not affect the city's layout which is orthogonal in its core. As John Hyslop (1990) noted, "it is still uncertain to what degree the Incas are actually portraying zeque systems (even) in radial layouts, or just the principles and spatial relationships found in the system."

Another reason why it may be difficult to extract generally applicable town planning rules is that the various settlements served different functions and were used in different ways. Ollantaytambo, Machu Picchu, and Patallacta discussed above were royal estates, that is the private property distinct and apart from state property, of the ninth Inca Pachakuti, and Calca was an estate of the Inca Waskhar. Cuzco, on the other hand was the all important capital of the Inca Empire, whereas Huánuco Pampa, like Tambo Colorado, was a regional administrative center in a newly conquered territory. The different types of settlements may have operated and functioned along different lines, such that any comparison may be spurious. Little is known about life in Inca settlements. Of Cuzco, Pedro Sancho de la Hoz, Francisco Pizzaro's personal secretary, wrote that it "was so large and so beautiful that it would be worthy of being seen even in Spain," and he added that it was "full of palaces of the lords, for in it there lived no poor people." What Sancho described referred probably only to the core of the city, for it is known that there were people from every corner of the empire also living in Cuzco. Of life in Cusco Protzen and Rowe (1994) wrote:

> Street life was probably limited to the movement of people from one place to another, with a stop perhaps for a bit of gossip, or to fetch water from the canals. There was no mercantile activity in the streets and there were no storefronts. Most residential and religious compounds [or *kancha*] were surrounded by walls with only one doorway giving access to the street. Supplies for sustenance of daily life were delivered directly from the state warehouses to the compounds. All production, weaving, wood and metal working, pottery, brewing, baking, and so forth was carried out within the compounds. On official occasions, civil or religious, the street scene may have been animated by parades and processions: the Inca being carried around town in his litter with the requisite entourage of nobles and bodyguards; the arrival of a dignitary from the provinces accompanied by llama trains loaded with gifts of all kinds; the triumphant return of a war party, with soldiers displaying their loot and parading prisoners; or a solemn religious procession, with priests in colorful attire carrying idols and other paraphernalia.

It is not known to what extent what happened in Cuzco can be extrapolated to other Inca towns. There are very few eyewitness accounts of life in other places of the Inca Empire. Little is known about the organization, function, and operation of royal estates. However, as in the case of Ollantaytambo, one can assume that there was a royal residence for the Inca and his immediate entourage, that there were accommodations for the accompanying nobility and administrators, and that there were quarters for the servants. Yet, the layout of the settlement, its size and its

architecture, suggest that it was more than just a rural retreat with its requisite appendices. It has the character of an agglomeration in which a population of perhaps a thousand people was permanently settled.

Discovering general planning principles may be, at least in part, also complicated because the principles, whatever they were, may have been altered to fit the specific features of a site and its topography.

In Cuzco, in spite of colonial modifications, the major features of the Inca plan can still be appreciated. The grid-like street pattern was squeezed and bent into the neck of land between the Watanay and the Tulumayo rivers to conform to the Puma shape. At Patallaqta the street pattern also is grid-like, yet it is shifted and broken to fit the crescent-shaped plateau on which it is built. At Machu Picchu, where the terrain is much more accidented, or broken, than at Patallaqta, the intent of an orthogonal layout can still be detected. Alleyways and staircases generally cross at right angles. The modifications brought to the layout are subtle adaptations to the specific topography. Streets and alleyways, like the terraces, follow the contour lines, and staircases follow the terrain's fall lines. The town occupies two natural ridges, and is completely split into two sectors by a plaza which is molded into the saddle between the ridges. The kancha are squeezed, stretched, and distorted to fit the available space on the terraces, as they do at Wiñay Wayna, about an hour from Machu Picchu.

One of the most striking site planning efforts, and some of the most spectacular adaptations of building forms to suit the particular terrain, are seen at Phuyupatamarka. The buildings literally grow out of the bedrock and espouse the terrain to become one with the site; the man-made world again is inseparable from the natural world.

Today's tourists, arriving at Machu Picchu by train and bus, miss one of the most important features of Inca site planning; they are deprived of the dramatic encounter with the site the ancient traveler experienced when coming through the gate of Intipunku. That encounter involves a succession of open spaces that are scaled from the vast horizons of the Andes to the intimate courtyard in town, strung together by narrow passages over precipitous cliffs, steep staircases, alleyways, and gates. Along this pathway the site is veiled and unveiled in a sequence of vistas that reveal the lay of the land and the setting of the town, and attract attention to details of nature or architecture framed by narrow passages or gates.

The gate of Intipunku affords a distant view of Machu Picchu, still too far away to discern individual architectural features, but close enough to grasp its general layout, and to appreciate its scenic setting and subtle incorporation into the majestic landscape. When one descends the trail from Intipunku, Machu Picchu disappears from view completely only to reappear in a succession of mere glimpses. Only when one rounds the bend in the trail, just below the so-called Watchman's House, does the site reveal itself again in its entire splendor, spread out immediately at one's feet with the sugar loaf peak of Wayna Picchu looming over it. Continuing down the stairway toward the main gate, most of the site vanishes again, and it is not until the very last step before the gate that Wayna Picchu is unveiled again in a dramatic view, perfectly framed by the gate.

Moving on through the site, one's view is alternatingly constrained by high walls bordering the alleyways and broadened as one emerges onto a staircase, a terrace, or an open space. There is a progression from the open and public spaces through narrow alleyways and gates to the enclosed and private spaces. At many junctures, one's attention is drawn to important features in the landscape. Sometimes this is achieved by narrowing one's field of vision, sometimes by widening it. The windows of the Temple of the Three Windows concentrate the view upon the half dome of Putukusi to the east and to the west the plaza, defined by the temple and the two buildings which flank it, opens wide to a sweeping view of the snow-capped Cordillera Vilcabamba and its many sacred peaks.

Machu Picchu is not unique in this; orientations upon features in the landscape are rather common in Inca architecture and can be observed at many other sites.

The rigid street grid of Ollantaytambo was by no means the norm for Inca settlements. Where regularity in the layout of the streets is found, it is probably a by-product of the rectangular design of the kancha, and not so much a reflection of the intent to parcel out the land in a grid. In accidented terrain the kancha and the building forms were "deformed" and modified to adapt to the topography, rather than made to conform to an abstract principle. While some commonalities and the repetition of certain elements can be observed at various sites, there is simply not enough empirical evidence available to induce a set of formal town planning rules by which, if they existed, the Incas laid out their settlements. It may be that the incorporation of views and the orientation on architectural and landscape features was the all-pervasive site and town planning criterion. To support this hypothesis, if it is at all tenable, many more sites will need to be analyzed dynamically; that is, as one moves through the sites rather than by merely investigating their plans.

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City Planning: Maya City Planning

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Much of ancient Maya civilization flourished in the period from AD 250–900 in the area encompassing the whole of Mexico's Yucatan Peninsula, the Mexican states of Chiapas and Tabasco, and the countries of Belize, Guatemala, western Honduras, and El Salvador. During the course of nearly twenty centuries of development, the distinctive architectural styles of the Maya heartland evolved and collapsed. As with other aspects of the Native American legacy, ancient Maya architecture was once seen as far too sophisticated to have been the product of aboriginal genius, and was long credited to Old World voyagers ranging from Egyptians to Israelites, and from white men or Danes to "great white Jewish Toltec Vikings" (Silverberg, 1968).

As scholarly knowledge of Maya architecture, settlement patterns, and city planning has grown exponentially over the course of the last 60 years, so too has our respect and admiration for this ancient American tradition (Morley, 1983).

Until quite recently, scholars perpetuated the belief that the Maya had neither a literate tradition or history, nor true cities or political economies. They often typecast Maya architecture as inferior, because it did not employ the "true" arch in the Roman sense. And they were unable to demonstrate that Maya centers were planned and constructed under the direction of professional architects with drafted plans. Given the geomantic principles, astronomical alignments, and geometric sophistication inherent in Maya cities, it would be more difficult to demonstrate that the Maya had no such architects or recorded plans. This review will begin with an overview of the role of astronomy, cosmology, and geomancy in Maya architectonic arrangements, and then move to a broader consideration of the question of site planning in the ancient Maya heartland.

Maya Architecture, Sculptural Programs, and Cosmology

Archaeologist and architectural historian H. E. D. Pollock has defined ten primary architectural and planning styles for the lowland Maya heartland. To these may be added another four highland Maya areas that I believe may be distinguished for the Quichean highlands of southern Guatemala, the Cotzu-malhuapan Pacific coastal tradition, the Middle Classic (AD 400–650) styles of Kaminaljuyu and vicinity, and the hybrid regional developments of the present-day state of El Salvador.

Where the Maya lowlands are concerned, Pollock describes the influence of environment and topography on planning and architectural layout:

> The flood plains of Copan and Quirigua; the flat or gently sloping banks of the Pasion River; the steeply rising hills along the Usumacinta River; the mountainous shelf of Palenque and alluvial plain of Comalcalco; the low, wet, but often sharply broken terrain of the Peten; southern Campeche; and southern Quintana Roo; the savannas, valleys, and hills of the Chenes and Puuc regions; and the flat northern Yucatan plain all offered different opportunities and challenges to the ancient builder.

Custom was mediated by local and regional environmental conditions and the adaptive traditions which arose from them. Clearly, civil planning developed well beyond the purely "organic" (Andrews, 1974) organization of monuments oriented to topographic and natural features of the immediate environment. Even in the earliest periods of Maya city planning, cosmological, astronomical, ritual, genealogical, and dynastic variables were integrated into site plans and construction programs. Plans were formulated in terms of multiple variables, not the least of which were the mechanistic dimensions of astronomical and cosmological cycles and dimensions, and the organic or topographic, and natural or practical realities of urban planning.

The period immediately preceding the Classic period was a time of great dynamism. According to archaeologist C. Bruce Hunter, "between 600 BCE and AD 250 great activity in city planning was taking place all over Mesoamerica. Cultural areas were defined, ceremonial complexes in the heart of the cities were constructed, and trade routes and luxury goods fostered trade competition between regions." Many of the greatest urban centers were built at this time. By the end of the Preclassic era – ca. AD 100 – Tikal and Uaxactun in the Peten lowlands and Cerros and Cuello in Belize had added to the architectural traditions of the era. The ancient cities of Dzibilchaltun in the northern lowlands, El Mirador in the southern lowlands, and Kaminaljuyu in the Guatemalan highlands defined the ceremonial construction for each of these subregions.

On the basis of recent glyphic transcriptions, we can now say that the iconography and architectural order inherent in the earliest city planning incorporated cosmological, dynastic, ritual, architectonic, and geomantic principles used in the organization of sacred geography and the built environment. My own study of the sculptural program embodied in the architecture and planning of the rock-cut temples of Malinalco, Mexico, and Carolyn Tate's more recent architectural survey of the ancient Maya center of Yaxchilan provides compelling evidence for

Mesoamerican site plans based on pre-Columbian solar configurations or cosmograms, as well as the use and deployment of solstice-based axial alignments in city planning (Mendoza, 1975; Tate, 1992).

Geomancy and Maya City Planning

Geomancy, referred to as "mystical ecology" and as cosmological ecology or sacred geography, was the ancient Chinese practice of situating burials, monuments, and entire towns on the basis of cosmological principles. Because ancient Chinese scholars documented this practice so extensively, it is largely identified with Chinese civilization, although recent studies make clear the use of geomancy in ancient Mesoamerica (Freedman, 1969).

Much of the divinatory practice embodied in geomancy is particularly relevant to Mesoamerican, and specifically Maya, city plans. According to John Carlson, geomancy is "a divinatory art involving the interpretation of local topographical features for the purpose of properly locating and orienting the constructions of man – be they graves, houses, or entire cities." However, Carlson has redefined geomancy as a:

> profound system of thought, deeply rooted in ancient and fundamental oriental philosophy and involving perception of the dynamic balance of the controlling forces of nature. It is the system in which man divines his own place in relation to the play of these forces, and it is the mechanism by which he can influence them in order to re-establish equilibrium when imbalance is perceived. (Carlson, 1981)

Maya city centers all provide archaeological evidence for the interpretation that plans were based on cosmological and geomantic models; however, few such sites have been examined with such principles in mind. Recent studies, such as those of William Rust (1992), Jeremy Sabloff and Gair Tourtellot (1992), Wendy Ashmore (1992), Robert Sharer (1990, 1992), and Carolyn Tate (1992), make clear the ancient Olmec connection to Maya ceremonial and settlement planning, the influence of changing economic and demographic patterns on planning, the icons of power, divinity, and divine mandates invoked through creation myths and expressed through architectural vocabularies and sculptural programs, the concentric patterning of civil monuments, and the deployment of solar cosmograms in site planning, respectively. We shall examine one site in detail.

Yaxchilan

The site of Yaxchilan, Chiapas, which overlooks the Usumacinta River separating Mexico from Guatemala, is one site that has been examined from the perspective of world plan as embodied in city plan. The site underwent dramatic transformations in construction during the reigns of Shield Jaguar, his father Bird Jaguar III, and his grandfather. The site was altered to establish "specific axes of solstitial orientation for architecture depending on the function of the building or space or the message of its sculptural program, and was conceived to define ritual areas used by particular rulers" (Tate, 1992). Yaxchilan was constructed on an elongated shelf and used terraces, tiers, and elevated plaza-platforms within the context of a larger acropolis-centered pattern. Yaxchilan also incorporated a series of hills into the larger plan of the site, and was situated in a position providing the only unobstructed vantage point from which to observe solstice alignments between major buildings and prominent mountain peaks – serving as clefts in the horizon and as points of astronomical reference. Other recent observations document that major buildings at Yaxchilan were devoted to rites of passage – particularly those pertaining to dynastic accession, succession, calendrically based Period Endings, and to the capture and sacrifice of living kings. Such monument are oriented with respect to the eastern horizon and the summer solstice, whereas funerary chambers and obituary monuments and stelae are oriented along solstitial axes pertaining to the winter solstice at 118° east of magnetic north. Several of the obituary

monuments and funerary shrines in question are aligned to 115–116°, as opposed to the more exacting 118° east of magnetic north; apparently so as to allow for the use of doorways with half-quatrefoil overhead jambs to provide for architectural-solar hierophanies, or light and shadow patterns serving to record the passage of summer and winter solstice events. Such information provides a direct correspondence with ancient Maya identifications of the summer solstice with royal and/or divine renewal and the planet Venus, and the cosmological association of the southern horizon with caverns as the portals to the underworld, the moon, and the land of the dead. The fact that Yaxchilan's southern precinct skirts the mouths of two prominent caves is cosmologically significant. According to Carolyn Tate, the caves "must have played a role in Bird Jaguar's decisions on how to shape the ritual landscape" (Tate, 1992).

Major buildings, monumental stelae, altars, and ritual markers from Yaxchilan all bear orientations that speak to political and ritual events. Buildings were aligned horizontally, and "situated from high to low vertically" (Tate, 1992). By employing "alignments of stelae that conceptually linked the reigns of successive rulers," the architects and planners coordinated the organization of the royal house of that era.

Recent studies at the sites of Tikal and Quirigua (Guatemala), Cerros (Belize), and Kohunlich (Mexico) provide dramatic examples of the means by which Maya world view and the realm of the supernatural were incorporated into city planning in a manner reminiscent of Christian, Muslim, Buddhist, and Hindu towns and cities of the Old World. While the sites of Cerros and Kohunlich provide architectural arrangements centered on monumental depictions of solar, lunar, terrestrial, and venusian cosmograms, the sites of Tikal and Quirigua incorporate these same dimensions in addition to those iconographic vocabularies and Twin Pyramid groups and precincts intended to symbolize the Classic Maya conception of the cosmos. Maya city planning has only recently undergone scrutiny with an eye to the larger mechanistic and organic dimensions and concepts of time and space inherent in Maya planning and design of the built environment. Wendy Ashmore has recently identified what she deems the five principle components of the Maya pattern pertaining to Tikal and related sites, these are (1) north-south axial arrangements, (2) complementary and paired functions of buildings centered along the main axes that serve to demarcate supernatural and celestial from underworld or terrestrial dimensions, (3) subsidiary eastern and western monumental arrangements within precincts providing for a triangulation with monuments located on the northern perimeter of individual precincts – and identified with the celestial vault and the cosmic tree of the north, (4) ball courts as transitional zones between north and south, and (5) the construction of causeways and paved roads linking precincts into a symbolically coherent cosmogram. To this listing I would add specific buildings that embody solar cosmograms and cosmic templates, as well as sculptural programs and iconographic vocabularies deployed across whole sites to imbue them with a sacred geography and cosmological ecology (Mendoza, 1977). We can no longer assume that the Maya built in a random and largely organic fashion – by accretion and accommodation as opposed to design and structure. Primitivist and eurocentric portrayals of the ancient Maya have eroded in recent years under the onslaught of a new world order reinterpreted on the basis of surviving hieroglyphic stairways, monumental texts, commemorative stelae, funerary shrines, frescoed murals, painted ceramics replete with textual information, and pre-Columbian and contact period codical documents and screenfold books. These sources are now providing a revolutionary perspective on the Maya (Schele & Freidel, 1990).

See Also

► Geomancy in China

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City Planning: Yorùbá City Planning

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The Yorùbá are a finite set of adjacent groups – including the Ègbá, Òndó, Àwórì, and Ìjèḅu – who share a mutually intelligible language, myths of origin, religious beliefs, cultural practices, experiences of bondage, and Anglo-Franco colonial heritage. Historians have argued that this ethnic identity coalesced in the nineteenth century, while their historical tendency to settle in large, densely populated cities and towns has pushed them to the forefront of discourse of indigenous urbanism in Africa. In West Africa today, Yorùbá-speaking people can be found split mainly between two countries, with over one million in southern Benin Republic and close to 40 million in southwestern Nigeria. Substantial minor communities are also established in Ghana and Togo.

Established as a confederacy of city-states thriving between the twelfth and the late seventeenth century, historically Yorùbáland maintained its autonomy and power – split between the political capital of Old Ọ̀yọ́ (Ọ̀yọ́-Ilé) and Ilé-Ifẹ̀, the religious center – by virtue of competitive advantages versus its neighbors. These advantages included sociopolitical organization, military alliances, and monopolization of ritual activity and commerce, especially in the light of its geographic position between the savanna plains of the hinterland and the forests close to the Atlantic coast (Usman, 2000).

MAP OF THE YORUBA COUNTRY
BIGHT OF BENIN
R. NIGER
R. Kaduna
R. Benue
R. Ogun
R. Oyan
R. Okpara
R. Weme
Nikki
Yashikira
Kaiama
Leaba
Parakhu
Halafia
Carhotville
Bojibo
Rabba
Jebba
Bida
Old Oyo
Ilesha
Ilorin
Ogbomosho
Offa
Oyan
Iseyin
Oyo
Oshogbo
Ede
Ilesha
Ife
Ibadan
Abeokuta
Ondo
Ifon
Kabba
Lokoja
Idah
Benin City
Agbor
Asaba
Onitsha
Sapele
Warri
Kwale
Ilaro
Ijebu Ode
Lagos
Porto-Novo
Badagry
Leckie
Ebute Metta
Ikorodu
Epe
Wida
Egga
Mekko
Zanyanado
Pawinya
Shaki
Saki
Scale 1:000000 or 1.014 Inches to 32 Miles
Miles 30 20 10 0
150 Miles
2° 3° 4° 5° 6° 7°
10° 9° 8° 7° 6° 5°

City Planning: Yorùbá City Planning, Fig. 1 "Map of the Yorùbá country" drawn by the Yorùbá historian Samuel Johnson (published 1921)

The collapse of Old Ọ̀yọ́ in 1835 and various Yorùbá kingdoms in the nineteenth century has been ascribed to both to pressures from the north by the consolidation of the Hausa-Fulani city-states and from the south by the growing involvement of the British missionaries, traders, and administrators in an era of the slave trade and its complexities. This was a time of disappearance and displacement of many classical Yorùbá cities (such as Ọ̀yọ́, which moved southward), reconfiguration of others (such as Ilorin, overtaken by the Sokoto Caliphate), and general decline. But it was also a time of reinvention and establishment of several prominent other cities such as Abẹ̀òkúta and Ìbàdàn (see Fig. 1).

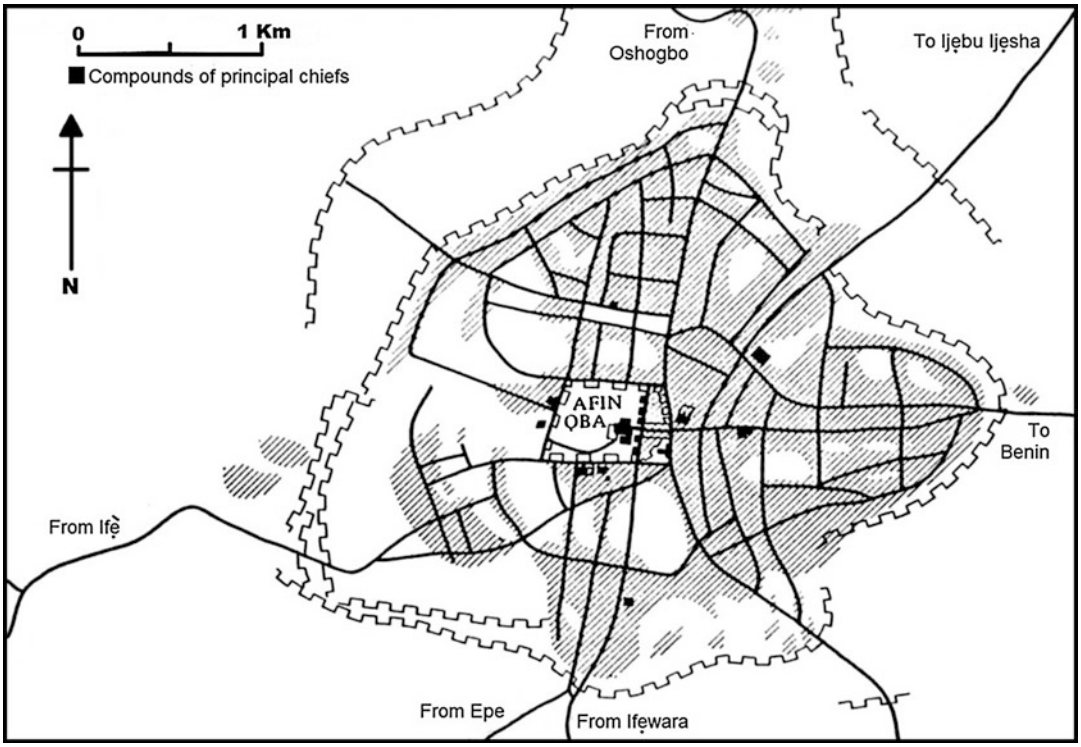
Yorùbá cities offer a paradox to Western scholars. As Africa had been traditionally considered by them as overwhelmingly rural or semi-rural at best, such conceptions were tied with other philosophies as the "noble savage"

imagery; research on preindustrial cities tended to focus solely on Western cities. In the rare cases where Yorùbá cities where mentioned in urban history works by the 1960s, they were designated as "semi-urban" (Coquery-Vidrovitch, 2005, pp. 12–13). Their markedly different modalities in form and function by comparison to cities in the West were saliently rooted, inter alia, in the use of temporary building materials and the lack of distinct division between urban and agricultural space. As a result, early debates among Western scholars centered on the idea of whether these settlements were cities at all (Sjoberg, 1960). These questions were settled from the 1970s and finally summarized by the basic premise laid by the urbanist Spiro Kostof, arguing that cities are places that are intimately engaged with the countryside and their separation is thoroughly injudicious (1999, p. 38). Since then, new debates about the longevity and morphology of Yorùbá cities have taken center stage.

The origins of Yorùbá cities are obscure, though local traditions, well documented by the Yorùbá-educated elite during the long nineteenth century, trace the origins of all Yorùbá to Ilé-Ifẹ̀. While this spiritual and urban focal point is estimated to date as far back as the ninth century, the circumstances of the original foundation of Ifẹ̀ itself are ambiguous (Law, 1984). The earliest recorded reference to Yorùbá settlements comes however from a Portuguese map in the sixteenth century, with Ìjèbu-Òde clearly indicated. Indeed, Yorùbá oral traditions of origins show some Islamic influence regarding geography and anthroponomy (Johnson, 1921; Law, 1984), an influence that is clearly reflected in the configuration and arrangement of historical urban layout (Moughtin, 1985). Surprisingly, no research exists examining the relationship between the oral and built traditions of the Hausa and Yorùbá.

Though there is little to no evidence for a centralized or top-down process of planning before the nineteenth century, many Yorùbá cities share remarkable morphological similarities. Though little evidence of individual planners or architects survives, what is clear is that these towns map a social and political reality that was fairly stable across different cities. The king (*Ọba*) was the political nucleus of each town, and thus, his palace or *àfin* was invariably the physical center. People and place were inextricably tied and tiered in the plotting of these cities. In this mapping, the classic or traditional Yorùbá city is a permanent, fortified settlement with an interior divided into distinct quarters settled by different distinct lineages, distributed along a spoke-and-wheel pattern arranged around the ruler's palace and main market. This spatial effect also reflects the ruler's centralized authority and the city's overall social organization (see Fig. 2). Anthropologists, namely, William Bascom (1955, 1969) and Peter Cutt Lloyd (1973) championed this Yorùbá urbanism model, and sociologists (Krapf-Askari, 1969; Mann, 2007), geographers (Mabogunje, 1969; Ojo, 1967), and historians (Aderibigbe, 1975; Oguntomisin, 1999) soon followed suit. Most recently, urban historians rendered in-depth visual narratives regarding Yorùbá cities such as Lagos, expanding on cartographic and planning modalities (Adelusi-Adeluyi, 2015 PhD dissertation; Bigon, 2009); critiques of the idealized premise of Yorùbá urban form also exist (Watson, 2003).

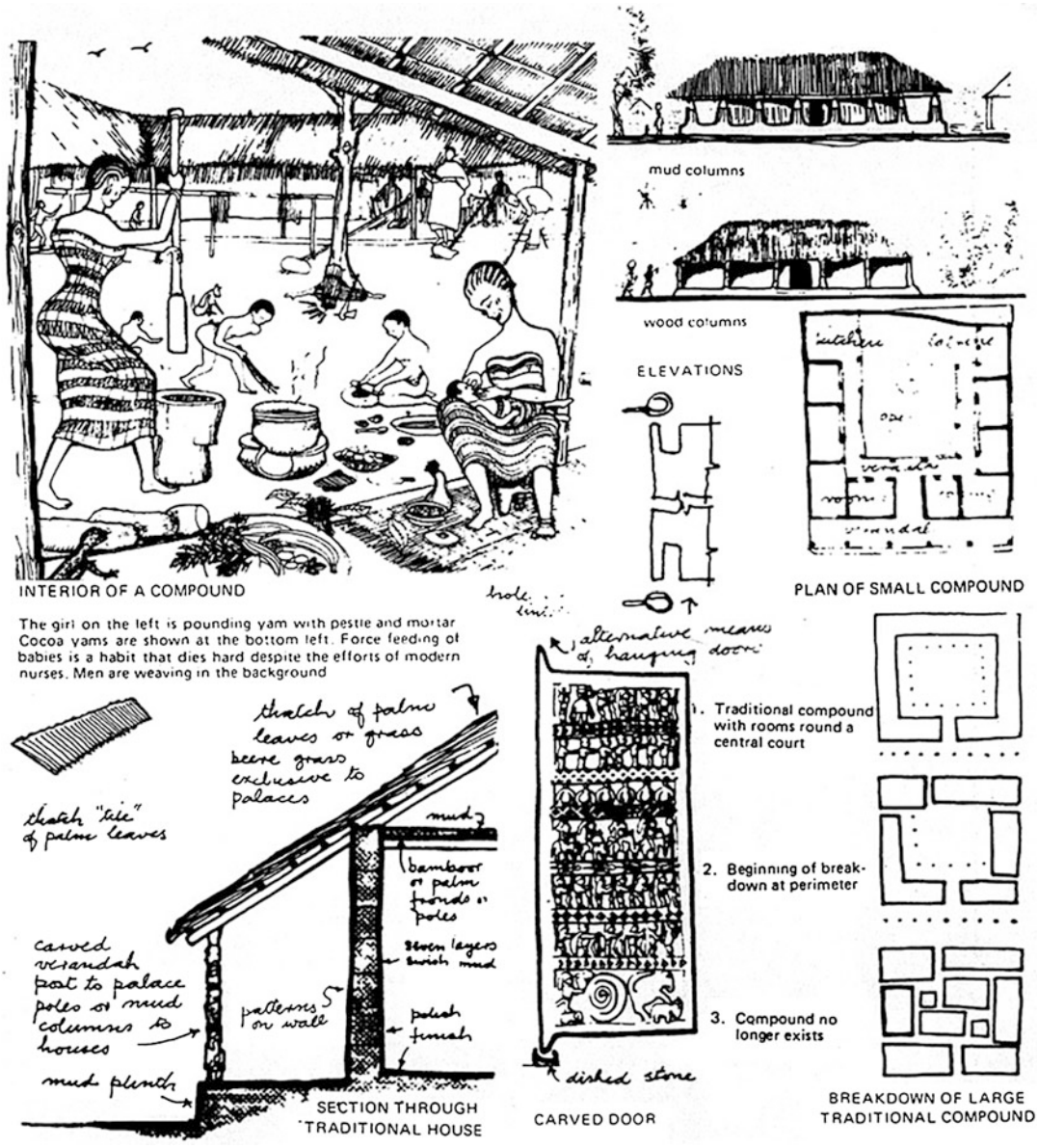
The cities (*ìlú*) are almost always oval in shape, with the Ọba's palace (*àfin*) normally as the focal point where the main roads and paths converge. Scholars point to Iléṣà as the "perfect formal representation" of the ideal spoke-and-wheel pattern of the Yorùbá city (Peel, 2000). Ọ̀yọ́, Òṣogbo, Ilé-Ifẹ̀, and Ọ̀wọ̀ are said to have had two or three concentric walls. Walls were punctuated with gates to control access, often serving as tollgates. In 1825, Lander and Clapperton reported that Old Ọ̀yọ́'s mud wall was 20 ft high, surrounded by a moat with a circumference of 15 or so miles. The nineteenth-century towns, often the hasty product of roaming, desperate refuges, depart quite dramatically from this ideal, most notably as a consequence of the circumstances of their formation. In Ìbàdàn, for instance, this meant an absence of a palace (Mabogunje, 1968), even though the main market (*Oja Iba*) still constitutes the heart of the old part of the city, now a polycentric and polymorphic conurbation.



City Planning: Yorùbá City Planning, Fig. 2 Town plan of Ilésà, an ideal plan of a Yorùbá city (Amended by the authors from Ojo, 1967)

The Yorùbá employ a complex urban vocabulary to differentiate between scale, population, and political importance (Ojo, 1966). Historically, a town's rank was based on a system of classification that privileged the existence of a crowned ruler at its nucleus. *Ìlú*, or city, refers not only to the town alone but to its political structure. Despite the importance of population and density, the most important factor to these urban inhabitants was its sociopolitical quality. For the Yorùbá, the *ìlú* or town was both town and polis. Ọ̀yọ́, Abẹ̀òkúta, and Ìjèbu have crowned kings whose authority is derived from Ilé-Ifẹ̀; hence, they are known as *ìlú aládé*. Cities lacking these rulers can be *Olu-Ìlú* or capital towns, such as Ìbàdàn and Ògbómòṣọ́. The *ìlú ọlọja* are market towns (e.g., Ẹ̀pẹ́ and Ejirin) and *ìlú-eréko* are dependent, subordinate towns (e.g., central Lagos, which is still known as *éko* in local parlance, as in the mid-seventeenth century, it became a vassal to Benin city and paid tribute). Finally, there are numerous *àgó* (war camps), *ileto* (villages), and *abúlé* (hamlets) scattered between the major and minor towns. This generic Yorùbá terminology of settlement forms and accompanied imagery has yet to be thoroughly studied, such as other specific toponyms that can teach us much on the spatial implications of the colonial encounter and the influence of global economy. One example is Ìbàdàn's Gbagi District, which designates the formerly white residential quarter, with *gbagi* meaning "to peg" in Yorùbá. This is due to a local fascination with the European preoccupation with title to land by pegging their plots, in marked contrast with communal land ownership and other indigenous conceptions regarding the central role of the land in the circle of life and death.

Among the other historic morphological characteristics, traditional public buildings such as small shrines could be identified in certain localities – to be later exchanged with more imposing mosques or churches. Within the



City Planning: Yorùbá City Planning, Fig. 3 Reconstruction of a precolonial Yorùbá compound made of perishable materials (Akinsemoyin & Vaughan-Richards, 1976, p. 8)

walls, periodic markets were an important economic feature and functioned as gendered spaces as women controlled many aspects of the economy (McIntosh, 2009). Residents of the city lived in differentiated quarters made up of grouped compounds. Houses, compounds, and walls were built of locally sourced materials, such as mud, country thatch, and other vegetation (see Fig. 3). These materials were later condemned by both Anglo and Franco colonial regimes, using building regulations as a tool for imposing capitalist economy and residential segregation on a racial basis between the expatriate and autochthonous societies, and slum clearance schemes (Bigon, 2008; King, 1995; Marris, 1961; Njoh, 2007).

City Planning: Yorùbá City Planning, Fig. 4 Late-nineteenth-century "Brazilian" house from Lagos, later roofed with corrugated iron; *below*: street scene from Ìbàdàn, showing *ilé petesy* variations (Photos: L. Bigon)

Yorùbá family compounds were most often built on a square plan, with numerous rooms surrounding an enclosed space in the center. The homes were bounded by a mud wall. These compounds were distinguished by size and rank, with their space increasing from half an acre for modest homes to many acres for chiefs, noblemen, and finally the largest space for the àfin (Izomoh, 1994).

During the mid-nineteenth and the twentieth century, a new vernacular domestic housing style evolved. It was initiated by ex-slaves of Yorùbá descent who returned to West Africa from Brazil. Using the masonry skills they acquired there, they developed the two-storey *ilé petesy* or "upstairs house" built with permanent materials and decorated in the baroque style. These Brazilian houses emerged first in Lagos (and simultaneously in other coastal towns like Porto-Novo) but gradually became naturalized all over Yorùbáland (Vlach, 1984) (see Fig. 4).

While cement-plastered rectangular compounds also characterize Yorùbá architecture, and the corrugated-iron roofing became so popular in dictating the reddish eroded cityscape today, a variety of deviations from traditional patterns also exist (Aradeon, 2012). Many of these changes initially took place during the colonial period and include the micro (residential unit) and macro (spatial urban expansion) levels, such as the filling in of the rectangular courtyard with built units and vertical, peripheral, and polycentric growth.

The first third of the nineteenth century was a time of dramatic upheaval for Yorùbá cities, mostly due to the effect of broken alliances and internecine wars. The emergence of Ìbàdàn and Abẹ̀òkúta in the first third of the nineteenth century showed a radical change in the conception and consolidation of urban Ifẹ̀ for Yorùbá people (Mabogunje, 1968; Smith, 1988). At least three important Yorùbá cities have roots in the wars of the nineteenth century, and these cities emerged from the efforts of refugee populations. These roots account for the ways that their morphologies departed from the ways that cities had been constructed in the past. Ìbàdàn and Abẹ̀òkúta, the most recent of the important cities, were both founded circa 1830. Old Ọ̀yọ́ was also relocated around this time. Owu, one of the largest Yorùbá cities, was destroyed by an Ìjẹ̀bu-Ifẹ̀ alliance, and the survivors from this city encamped in a deserted village. It was on this site that a new city, Ìbàdàn (roughly "war camp"), was built. Around the same time, Ègbá refugees fleeing south camped around Olumọ Rock, building Abẹ̀òkúta (meaning "under the rock"). Ìbàdàn was a new sort of Yorùbá town, borne of the circumstances of the fragmented internecine wars that ravaged Yorùbáland. Its population was made up of people from Ifẹ̀, Ọ̀yọ́, and Ìjẹ̀bu. The quarters and compounds were comprised of what John Peel (2000) termed non-kin affiliates, and there, the compounds no longer corresponded simply to grouped lineages.

Yorùbá cities differed in size and scale. Though no official census figures survive for the nineteenth century, visitors to Yorùbáland recorded several towns with over 10,000 inhabitants, with at least 22 towns numbering over 10,000 residents. Estimates for medium-sized towns like Ìjẹ̀bu Òde, Lagos, Ògbómọ̀ṣọ́, and Ìjàyè ranged from 20,000 to 40,000 in the 1850s. The larger cities – Abẹ̀òkúta, Ìbàdàn, Òṣogbo, and Ilorin – each numbered over 60,000. In the 1850s, Ìbàdàn's population was estimated at between 70,000 and 100,000, and estimates of Abẹ̀òkúta's population were most often set at 60,000, though one observer (Richard Burton) guessed that there were possibly 100,000 residents within the town's walls in 1861 (Mabogunje, 1968). Today, Nigeria (Africa's most populous country) accounts for about 18 % of the continent's total population, and thriving Yorùbá cities such as Lagos are estimated as among the fastest-growing cities in the world. Metropolitan Lagos, for instance, which in the 1950 consisted of only about 290,000 inhabitants, is expected to reach, according to UN HABITAT, to close to 20 million residents by 2025 (2014, p. 103).

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Clocks and Watches

Donald R. Hill

There was a long tradition in the Hellenistic world for the construction of large water clocks. Vitruvius, writing in the first century BCE, mentions the water clocks constructed by an Alexandrian engineer called Ctesibius (ca. 300 BCE) which incorporated gearing, automata, and audible time signals. The Alexandrian writer Hero, who flourished around AD 60, is known to have written a book on water clocks. The Byzantine historian Procopius described a monumental water clock constructed at Gaza in the sixth century AD. It is almost certain that the inspiration for the construction of water clocks in the Islamic world came from this Hellenistic tradition.

Islam

Monumental water clocks are described in detail in two Arabic treatises. ▶ Al-Jazarī in his machine book *Kitāb fī maʿrifat al-ḥiyal al-handasiyya* (The Book of Knowledge of Ingenious Mechanical Devices), completed in Diyar Bakr in 1206, describes two such machines. Riḍwān ibn al-Saʿātī, in his treatise *Kitābʿamal al-sāʿāt wa 'l-ʿamal biha* (Book on the Construction of Clocks and on Their Use) dated 1203, describes the water clock built by his father Muhammad at the Jayrun gate in Damascus. It fell into disrepair after Muhammad's death and was restored to working condition under his son's supervision. It was a large construction, having a timber working face about 4.73 m wide by 2.78 high, built into the front of a masonry structure. The clock had several design defects which undoubtedly caused the breakdown that Riḍwān undertook to repair. Moreover, Riḍwān himself was not an engineer and his description, though containing some valuable information, omits to deal with some important constructional details.

Al-Jazarī's two clocks, on the other hand, were manufactured and constructed in a very workmanlike manner. Although very similar in principle to al-Saʿati's they did not incorporate any design defects. The first and larger of the two was described in such careful detail that it was possible to construct a full-size working facsimile from al-Jazarī's instructions and illustrations for the World of Islam Festival, in the London Science Museum in 1976.

The working face of the clock consisted of a screen of bronze or wood about 225 cm high by 135 cm wide set in the front wall of a roofless wooden house which contained the machinery. At the top of the screen was a zodiac circle about 120 cm in diameter, its rim divided into the 12 signs. It rotated at constant speed throughout the day. Below this circle were the time-signaling automata which were activated at each hour. (The clock worked on "unequal" hours: i.e., the hours of daylight or darkness were divided by 12 to give hours that varied in length from day to day.) These included doors that opened, falcons that dropped balls on to cymbals and the figures of five musicians – two drummers, two trumpeters, and a cymbalist. The musicians were operated by the discharge of water from an orifice, whereas all the other automata were operated by a heavy float that descended at constant speed in a reservoir.

A cord tied to a ring at the top of the float led to a system of pulleys that activated various tripping mechanisms.

The speed of descent of the float was controlled by very ingenious water machinery that included a feedback control system and a flow regulator, the latter for varying the rate of discharge daily in order to produce the "unequal" hours. The same system was used by Riḍwān and both writers attribute its invention to Archimedes. There is a treatise that exists only in Arabic and is attributed to Archimedes. The treatise almost certainly contains Hellenistic, Byzantine, and Islamic material but its first two chapters describe water machinery that is essentially the same as that used by Riḍwān and ► al-Jazarī. There is every likelihood that these chapters were indeed the work of Archimedes.

Al-Jazarī's book also contains descriptions of four other water clocks, two of which embody the principle of the closed-loop, and four candle-clocks which, on a small scale, are as impressive from an engineering point of view as the water clocks.

Other Arabic works add to our knowledge of Islamic hydraulic timekeeping. A certain Ibn Jalaf or Ibn Khalaf al-Murādī worked in Andalusia in the eleventh century. Unfortunately, the unique manuscript of his treatise on machines is badly defaced, but it is possible to determine the essential details of the automata and water clocks that are described in it. The most important feature that they incorporate is complex gear-trains which include segmental gears (i.e., gears in which one of the wheels has teeth only on part of its perimeter, a device that makes intermittent action possible).

Al-Khāzini's justly famous book on physics, *Kitāb Mīzān al-Ḥikma* (Book of the Balance of Wisdom) was completed in 1121–1122. In the eighth treatise two steelyard clepsydras are described. On the short arm of the beam was a vessel that discharged water at a constant speed from a narrow orifice. Two sliding weights were suspended to the long arm, which was graduated into scales. At a given moment the weights could be moved to bring the beam into balance and the time could then be read off from the scales.

A number of noteworthy references to water clocks can be found scattered among the works of Arabic writers. For example, we read of one such device in the works of the Anadusian poet ʿAbbās ibn Firnās (d. 887). Two water clocks were constructed by the famous astronomer al-Zarqallu in 1085 on the banks of the river Tagus at Toledo. The remains of two large water clocks still exist in Fez, Morocco. One of these is in the street opposite the Bu'ananiyye Madrasa and was built in 1357. According to the historian of Fez, Al-Jazna'ī in *Zahrat al-Ās*, at each hour pellets fell onto a gong and a pair of door leaves opened. The door openings and the brackets for the gongs still exist. A second clock was constructed in 1361. It had an astrolabic dial and it also released pellets and had doors that opened. It is in the minaret of the Qarawiyyīn mosque. The doors and the dial still survive, but in neither of the Fez clocks does any trace of the water-machinery remain. Another North African water clock, in Tlemcen, was mentioned by Abū Zakariyyā Yaḥyā ► ibn Khaldūn in *Bughyat al-ruwwād*.

In 1276–1277 a work entitled *Libros del Saber de Astronomia* was produced in Castilian under the sponsorship of ► Alfonso X of Castile. This consists of various works that are either translations or paraphrases of Arabic originals. It includes five timepieces, one of which is of significance in the history of horology. This consisted of a large drum made of walnut or jujube wood tightly assembled and sealed with wax or resin. The interior of the drum was divided into 12 compartments, with small holes between the compartments through which mercury flowed. Enough mercury was enclosed to fill just half the compartments. The drum was mounted on the same axle as a large wheel powered by a weight-drive wound around the wheel. Also on the axle was a pinion with 6 teeth that meshed with 36 oaken teeth on the rim of an astrolabe dial. The mercury drum and pinion made a complete revolution every 4 h and the astrolabe dial made a complete revolution in 24 h.

This type of timepiece had been known in Islam since the eleventh century.

China

The commonest method of timekeeping in China, for many centuries, was the inflow clepsydra. In its simplest form this consisted of two vessels: a reservoir and a receiver below it. The reservoir had an overflow pipe near its top and an orifice in its underside. The water supply ran into the reservoir and the overflow pipe ensured that the water level remained constant. The rate of flow from the orifice into the receiver was therefore also constant as was the rise of the water in the receiver. A float in the receiver was used to activate various time-recording mechanisms.

The inflow clepsydra was used extensively in China from the Han period (202 BCE–AD 221) onwards. Two main types were developed. The first type involved the introduction of one or more compensating tanks between reservoir and receiver. At each successive stage the retardation of flow due to diminishing pressure head was more and more fully compensated. The introduction of at least one compensating tank can be dated to the second century AD. As many as six tanks are known to have been used. In the second type an overflow or constant head tank was placed in the series, a practice that began in the middle of the sixth century AD. There can be no doubt that this type of water clock was widely used in China throughout the medieval period.

The most notable achievement of Chinese horologists was the clock described by Su Song in *Xin yixiang fa yao* (New Design for an Armillary Clock or Description of a New Astronomical Instrument) begun in 1088 and completed in AD 1094. This was a monumental clock, 30–40 ft (9–12 m) in height, having a rotating armillary sphere and celestial globe, together with numerous jack-work figures with both audible and visible effects. These devices were driven, through a complex system of gearing, by a water-wheel 11 ft (3.35 m) in diameter carrying 36 scoops on its perimeter. Water stored in an upper reservoir was delivered to a constant-level tank by a siphon, whence it was discharged on to the scoops of the wheel, each of which had a capacity of 0.2 ft^3 (0.6 cm). The wheel was provided with a very ingenious escapement system, in essence two steelyards upon each of which the scoops acted in turn. When a scoop was full, its weight overcame the balancing system and it fell freely for a given distance until checked, without recoil, by a locking device. The next scoop then came under the delivery jet and the cycle repeated itself. There is no evidence that the system of escapement used in Su Song's clock was ever transmitted westward.

The mechanical clock was invented in western Europe toward the end of the thirteenth century. Almost certainly its inventor came from the ranks of the makers of water clocks. The verge escapement made the mechanical clock possible, but all its other features – weight-drive, automata, gear-trains, and segmental gears – were present in Islamic water clocks. It is highly probable that these ideas were transmitted from Islam to the European makers of water clocks. An Islamic influence on the genesis of the mechanical clock may therefore be postulated.

Several of Taqī al-Dīn's writings are concerned with timekeeping, and one of these, *Al-kawākib al-darriyya fī al-binkāmāt al-dawriyya* (The Brightest Stars for the Construction of Mechanical Clocks), written about 973/1565, has been edited with Turkish and English translations.

In this he described the construction of a weight-driven clock with verge-and-foliot (an early form of balance) escapement, a striking train of gears, an alarm, and a representation of the moon's phases. He also described the manufacture of a spring-driven clock with a fuzee [a conical pulley or wheel] escapement. He mentions several mechanisms invented by himself, including, for example, a new system for the striking train of a clock. He is known to have constructed an observatory clock and mentions elsewhere in his writings the use of the pocket watch in Turkey. This is a surprisingly early reference to the use of watches in Turkey; the manufacture of watches began in Germany about 1525 and in England about 1580.

Taqī al-Dīn's descriptions are lucid with clear illustrations, showing that he had mastered the art of horology. Clockmaking did not, however, become a viable indigenous industry and Turkey

was soon being supplied with cheap clocks from Europe. ► Taqī al-Dīn himself commented on the low price of these European clocks, which entered Turkey, he said, from Holland, France, Hungary, and Germany.

See Also

► Alfonso X
► Al-Khāzinī
► Ibn Al-Zarqāllu
► Ibn Khaldūn
► Taqī al-Dīn

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Clocks: Astronomical Clocks in China

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Timekeeping was a necessary preoccupation of the Chinese imperial state from its inception in the third century BCE. It was essential to the effective performance of ritual, which required the selection of auspicious hours as well as days, and to the proper interpretation of the astrological portents carefully recorded by the Astronomical Bureau. In addition it underpinned the fine tuning of increasingly elaborate systems of mathematical astronomy. The earliest devices used by astronomers were simple outflow or inflow waterclocks (clepsydras), which depended on the flow of water from a vessel to a small orifice. A graduated float indicated the time elapsed. Several later sources mention the Han dynasty scholar ► Zhang Heng (AD 78–139) as having succeeded in rotating an armillary sphere by means of "flowing water" so that it kept time with the heavens.

More detailed accounts survive of a similar project under the Tang dynasty in the eighth century AD, when the Buddhist monk Yixing and his colleague Liang Lingzan made a water-powered armillary sphere, which incorporated jack-work to announce the hours and quarters by bells and drums. In neither case we have enough data to begin to reconstruct the mechanism involved. However, in AD 1086 the high official and scholar Su Song was commissioned to construct an astronomical timekeeper which was to be much more complex than any of its predecessors, and a detailed illustrated description of this device has come down to us in his monograph entitled *Xin yixiang fa yao* (Description of a New Astronomical Instrument or New Design for an Armillary Clock).

From this book we learn that the device Su Song constructed was in effect a clock-tower more than 10-m high, surmounted by a great bronze armillary sphere automatically rotated, with a rotating celestial globe in an inner

chamber. On the front of the tower was a complex array of jacks and annunciators to mark the passage of time. The mechanism which turned the shafts was based on a great water-driven scoop wheel, with a weighbridge and trip-lever movement which allowed the wheel to advance one step each time a standard weight of water had run from a constant-head tank. This happened once every hundredth of a day, about 15 min, so that the correspondence with the heavens was somewhat jerkily maintained. While the utility of this device to astronomers can only have been moderate, its possession must have been seen as a considerable enhancement to imperial prestige. Su Song's tower fell out of use when the capital fell to invaders in AD 1126.

See Also

- ► Calendars in East Asia
- ► Divination: Science, Technology, and the Mantic Arts in Traditional China
- ► Zhang Heng

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Cloth Making at Chichen Itza

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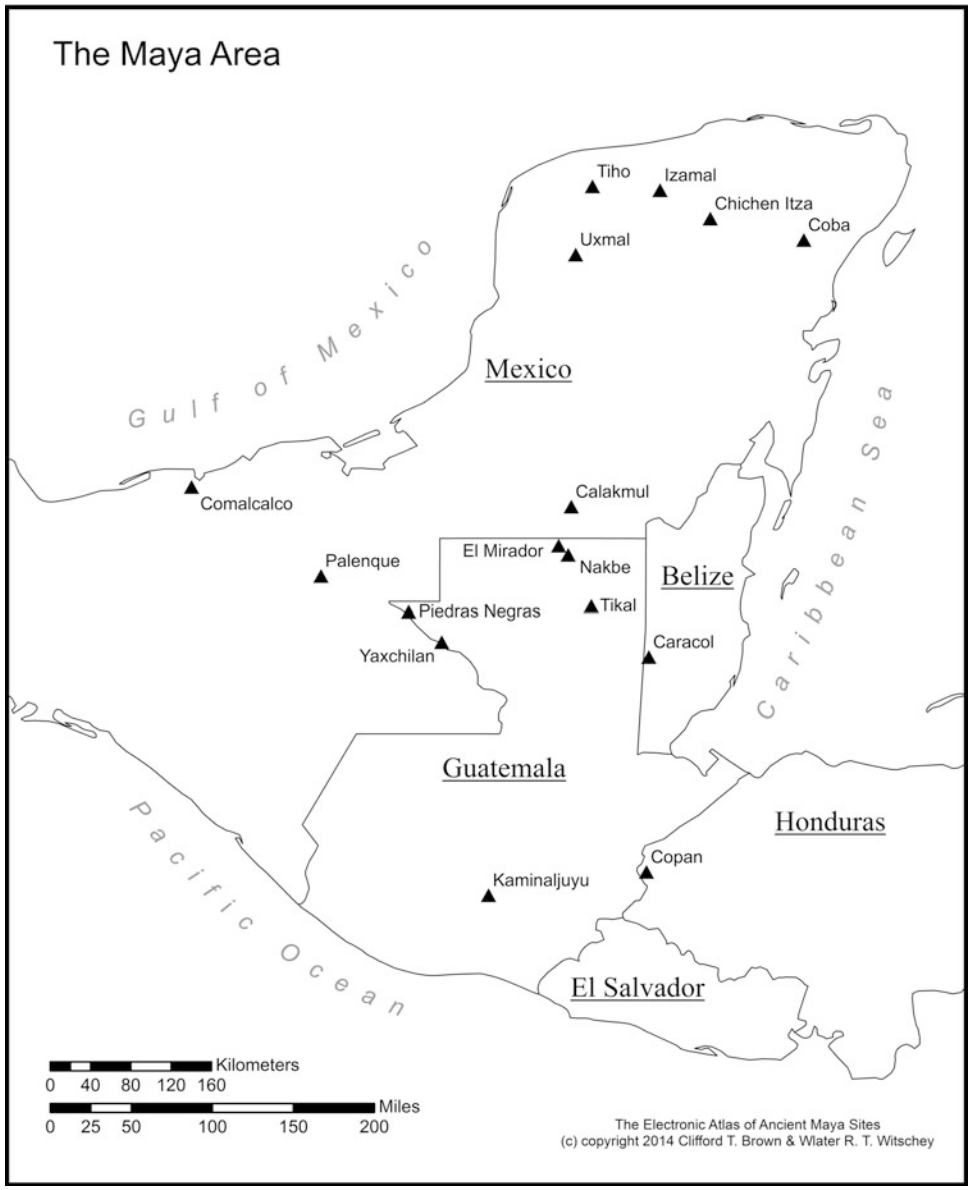
The manufacture of cloth is a tradition with deep roots throughout the Maya area (Fig. 1), which encompasses the Yucatán Peninsula or northern region, and the area south of this, comprising what are today the Mexican states of Tabasco and Chiapas, Guatemala, Belize, and parts of Honduras. Because of the humid nature of the climate characterizing much of the Maya area, few textiles survive from the pre-Hispanic time period (i.e., prior to the sixteenth century). The largest collection that does, however, comes from the Sacred Cenote at Chichén Itzá. Over 600 fragments of textiles were found in the early twentieth century dredging operations at the cenote (a natural pit or sinkhole resulting from the collapse of limestone bedrock that exposes groundwater underneath), most of them only a couple of centimeters in size. They exhibit a variety of weaves, although a plain weave is the most common (Lothrop, 1992; Mahler, 1965). The original provenience and dating of the Chichén textiles remains unknown, as pilgrims came from great distances to make petitions and leave offerings as payment to the deities over a period of time that likely spanned a millennium (Lothrop, 1992). Many of these were bundled or wrapped in cloth (Fig. 2).

The question of where textiles were being manufactured can be answered by archaeological evidence, primarily that provided by the recovery of specialized tools. The most common of these are spindle whorls, which consist of a round disk that is attached to the base of a spindle to serve as a weight when fibers are being spun to create thread, and bone implements that may have served as weaving picks. Spindle whorls may be made of various materials, including stone, bone, baked clay, or wood; the latter is rarely found in archaeological contexts, however, because of their perishable nature. Clay spindle whorls recovered in Yucatán appear to have been mold made and have a variety of designs, the most common being four-part compositions (including flowers) and birds (Fig. 3).

Spindle whorls have been recovered from a number of Maya sites, both in the northern region (where Chichén Itzá is located) and further south, at sites such as Caracol, Copán, and Motul de San José (Chase, Chase, Zorn, & Teeter, 2008; Halperin, 2008; Hendon, 1997). The largest concentrations come from the Late and Terminal Classic periods (c. 600–1000 CE). Analyses of these artifacts provide a great deal of information about weaving technology, gender roles, and production techniques over time and across the Maya area.

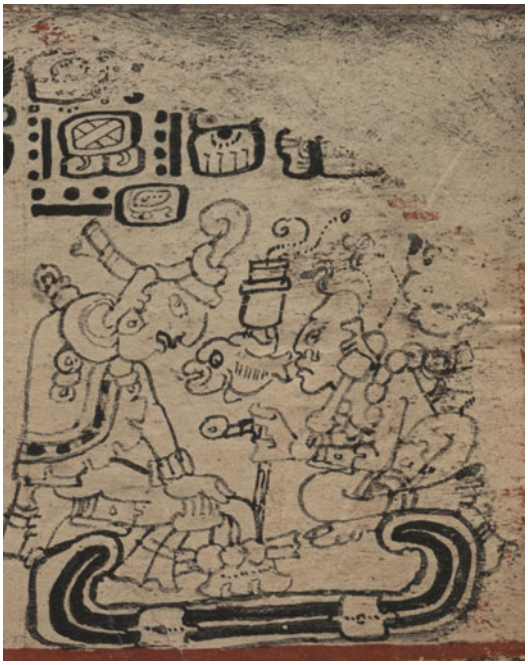


Cloth Making at Chichen Itza, Fig. 1 Map of the Maya area, showing the major sites mentioned in the text. Balankanché and Xuenkal are located in the vicinity of Chichén Itzá (Brown & Witschey, 2014)

The technology employed by the pre-Hispanic Maya in producing textiles has changed little over the millennia, as suggested by depictions of weavers in three-dimensional media, such as figurines and whistles, as well as painted in screenfold books called codices. The first step would have involved the gathering of fibers (cotton and hemp were two that are known to have been used pre-Hispanically) and their processing to clean and prepare them for use. The processed fibers were then spun to create thread, using a process similar to that illustrated here (Fig. 4); they were also sometimes dyed, either before or after spinning, using various plants and mineral substances. Prior to being woven, the threads had to be warped in a figure-8 pattern,

using a warping frame, as shown in this image from the Madrid Codex (Fig. 5). They were then soaked in a corn gruel to strengthen them, before being transferred to the loom.

The type of loom used by the pre-Hispanic Maya, referred to as a backstrap loom, differs little from that used by their descendants today. It consists of a collection of sticks and a strap. Eight sticks are commonly used in contemporary Maya backstrap looms, including the front and back bars, the heddle rod, the shed rod, shuttle, batten, tenter, and lease stick (Fig. 6). Pre-Hispanic looms (Fig. 7) were likely very similar in their design. One end would be attached by a rope to a tree or post and the other to the strap worn by the weaver to increase or decrease the tension when weaving.



Cloth Making at Chichen Itza, Fig. 2 Two deities making offerings to a cenote (represented by the U-shaped glyph) on page 33a of the Dresden Codex. The figure on the *left* offers a cloth-wrapped bundle (Förstemann, 1880)

Archaeological Evidence of Textile Production

The largest assemblage of spindle whorls recovered from the northern lowlands comes from Chichén Itzá itself (a total of 147), followed by the nearby sites of Xuenkal (25 total) and Balankanché Cave (26 total). The bulk of these collections come from Terminal Classic contexts, suggesting an intensification of textile production during this period, likely as the result of the transition from primarily household production to production for tribute and trade networks (Ardren, Manahan, Wesp, & Alonso, 2010). The largest concentration from Chichén (31) was found in the structure called Las Monjas, suggesting that spinning and weaving took place there on a regular basis. Because it has been identified as a primary residence for some of the more important women of the site, researchers have proposed that spinning was a prerogative associated with elite women at Chichén (Krochock, 2002, p. 160). Data from other sites

Cloth Making at Chichen Itza, Fig. 3 Spindle whorls from Balankanche'. Both depict birds, which played an important role in narratives relating to the moon goddess (who is frequently shown spinning and weaving in her human form) and her lover the sun, who appears in the guise of a bird (Andrews, 1970)

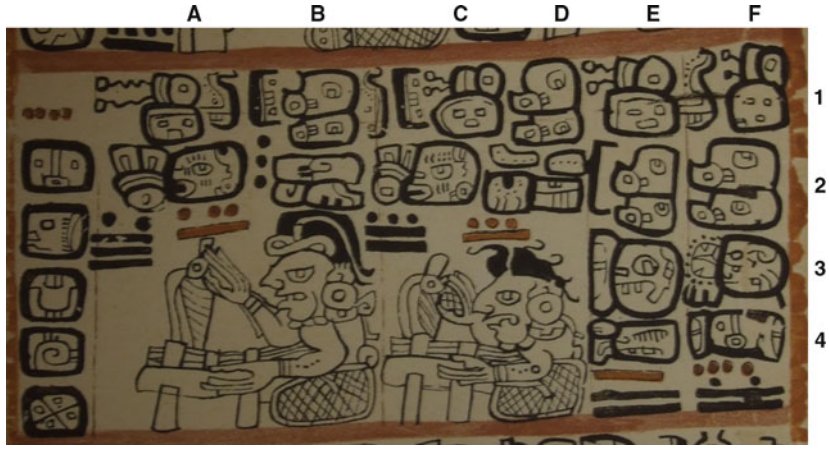
and archaeological contexts – principally burials – suggest that this correlation was true in other regions as well. It is likely that elite women produced fine cotton thread that was used for weaving ceremonial garments and those for the nobility and that women of other classes spun and wove with coarser materials for household (or community-wide) consumption.

Cloth Making at Chichen Itza, Fig. 4 The spinning of wool to create thread. Wool was introduced by the Spanish; prehispanic Maya women would have spun cotton or other fibers into thread (Photograph by Nicholas Manting-Brewer. With permission)

Xuenkal, located approximately 45 km from Chichén along the most direct route to its port facility, underwent a number of transformations during the Terminal Classic period, at a time when Chichén exerted its influence over a large portion of the surrounding region. Changes in the material inventory, along with new types of structures found at Chichén, suggest that the residents of Xuenkal either voluntarily or forcibly became part of the Chichén sphere of influence (Ardren et al., 2010).

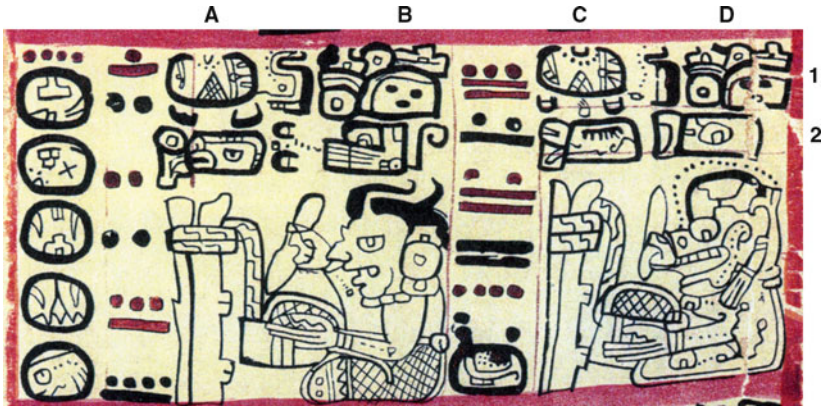
The recovery of 17 ceramic spindle whorls from one of the Terminal Classic platforms at the site suggests that it was a locus for textile production. An analysis of the whorls indicates that they were likely used for the production of fine cotton thread (based on the size of the spindle whorl and the diameter of the hole; larger examples were used for spinning coarser fibers, such as maguey). Ardren et al. (2010, p. 284) interpret these data as indicating the spinning of high-quality cotton thread, likely for the production of textiles to be given in tribute to Chichén. The question of whether weaving, as well as spinning, was done at the site remains unknown.

Xuenkal and Chichén are located in an area where cotton was grown in both pre-Hispanic and colonial times (Gates, 1978). According to colonial period sources, the manufacture of cotton *mantas*, or lengths of cloth, was one of the principal activities of Maya women, and the trading



Cloth Making at Chichen Itza, Fig. 5 The use of a warping frame (*chuch*) on page 102c of the Madrid Codex. The word *chuch* is spelled in the hieroglyphic text at B1 (Brasseur de Bourbourg, 1869–1870)

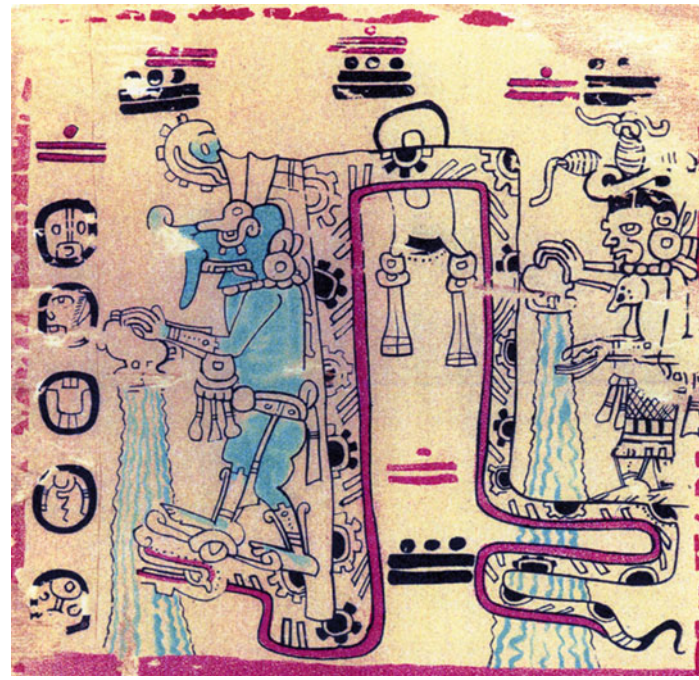
Cloth Making at Chichen Itza, Fig. 6 Maya weaver Concepción Poou Tharin illustrating the use of the backstrap loom (Photograph by the author)



Cloth Making at Chichen Itza, Fig. 7 Weaving with a backstrap loom on page 102b of the Madrid Codex. The cloth being produced is referred to at B2 in the text as *y-al*, "her child" (Brasseur de Bourbourg, 1869–1870)

of textiles was second only to that of salt (Landa, in Ardren et al., 2010, p. 275).

In addition to their practical uses, spindle whorls also have ritual and symbolic associations. In Group III at Balankanché, 25 spindle whorls were recovered, in association with a number of vessels for burning incense. As Vail and Hernández (2012) note, they were likely deposited as part of rituals related to the recreation of the world, which emphasized the creation of humans and of the rains to sustain them. The *incensarios*, which have modeled images of the rain god, were probably used to burn incense to create dense clouds of smoke to imitate the rain-laden clouds that gather during the rainy season, whereas the spindle whorls are indicative of the Maya creator goddess Chak Chel, who wears spindles wound with thread in her hair (Fig. 8). Among contemporary Maya cultures living in the highlands of Guatemala, the creator goddess is said to have woven the world into existence (Prechtel & Carlsen, 1988). Additionally, in highland Chiapas today, the daughters of the earth lord are responsible for fluffing cotton for spinning, which then escapes into the sky to form rain clouds (Morris, 1987).



Cloth Making at Chichen Itza, Fig. 8 Chaak and Chak Chel as rain-makers on page 31a of the Madrid Codex. Note spindles wound with thread worn by Chak Chel (Brasseur de Bourbourg, 1869–1870)

The presence of such a large number of spindle whorls in Group III at Balankanché, paired with the incense burners, suggests that they form a symbolic part of a rainmaking ceremony dedicated to the rain god Chaak and to Chak Chel (Vail & Hernández, 2012). The two are portrayed as bringing the life-giving rains in several almanacs found in the Maya codices (see Fig. 8), which are believed to date to the Late Post-Classic period (c. 1250–1500) and to come from Yucatán.

Use of Pre-Hispanic Textiles

Textiles appear in a variety of contexts during the Classic period (c. 250–800) in the southern Maya lowlands: as clothing worn by elite members of society (as seen on stone monuments, pottery vessels, and murals), as curtains and room dividers in palaces, as tribute given to the ruler of Classic period kingdoms, and as gifts cementing elite relations (Looper, 2000; Reents-Budet, 2002). Additionally, remnants of cloth have been found in Classic period tombs, where they appear to have served as wrappings for the bodies (Hendon, 1999). Cloth also played a significant role in rituals. Sacred objects and deity effigies were wrapped to contain their power when not in use and unwrapped for particular ceremonies, such as the accession of a ruler to office (Reents-Budet, 2002, p. 115).

Images from Classic Maya art and monuments stress the importance of clothing in defining social roles and gender identity. Special accoutrements were worn ceremonially, including headdresses of various forms (made of cloth and feathers) and jewelry (primarily of jade). In certain regions, women wore a long garment called a *huipil* when performing ceremonial functions (Fig. 9); in others, a type of netted skirt and top were more common. Elite women and men are both depicted wearing capes. Men of all classes wore loincloths, and women wore skirts or wrap-around (sarong-like) garments (Looper, 2000). Evidence from the Aztec region of Mesoamerica indicates that only the upper classes wore garments made of cotton, whereas other fibers (such as maguey, or agave) were used for the clothing

Cloth Making at Chichen Itza, Fig. 9 Elaborately decorated *huipil* worn by Lady K'ab'al Xook, queen of Yaxchilan in the eighth century. She performs an act of auto-sacrifice (a bloodletting ritual) by drawing a rope studded with thorns through her tongue (Photograph by the author)

worn by commoners (Anawalt, 2000, p. 207). It is not known whether this was the case in the Maya region as well, and if so, in what particular areas or time periods.

Textiles recovered archaeologically display a number of decorative techniques, including brocading, embroidery, and painting (Hendon, 1999), but the question of when these techniques came into use remains a matter of debate. Brocading and embroidery had developed by the Late Post-Classic period (c. 1250–1500), but it is unclear if they were used before then. Although some scholars have suggested that elaborately decorated garments depicted in pre-Hispanic stone sculptures may have been made by brocading (see Fig. 9), others argue that the intricate designs were made instead with a cylindrical stamp that was rolled across the cloth to create the very even patterns seen (Looper, 2000, p. 8). Maya women in Chiapas today reproduce these designs in a brocade technique (Fig. 10), and brocading may be represented in the Madrid Codex (Fig. 11).

Discussion

At the time of the Spanish conquest, the manufacture of textiles was one of the most significant economic practices in the northern Maya region.

Cloth Making at Chichen Itza, Fig. 10 Maya weaver from Chiapas brocading a series of prehispanic designs (Photograph by Nicholas Manting-Brewer. With permission)

Cloth Making at Chichen Itza, Fig. 11 Possible example of brocading using a weaving pick from page 79c of the Madrid Codex (Brasseur de Bourbourg, 1869–1870)

Archaeological evidence suggests that weaving fine cotton cloth was a high-status activity in earlier time periods, associated with the upper echelon of Maya society, and that cloth was being produced not only for household consumption but also for tribute and trade (Ardren et al., 2010; Hendon, 1997). Because all known artistic depictions show females performing the tasks associated with cloth production (spinning, warping, and weaving), researchers conclude that Maya women primarily did these activities. In light of this, the depiction of women's garments on Classic period monumental sculpture provides evidence not only of female status but of women's economic power as well (Looper, 2000, p. 17).

Among Maya cultures today, as was likely true in the past, men are responsible for providing the raw materials, which are then transformed by women into those things needed to sustain the family (cooked food, woven textiles, etc.). This can be likened to procreation and childbirth – although both partners contribute, it is the woman who ultimately gives birth to the child. Weaving is seen as analogous to giving birth, and the creator grandmother is said to have given birth to the world by weaving it into existence. Maya women from parts of Guatemala today likewise believe that a textile is born through the process of weaving (Prechtel & Carlsen, 1988). A similar belief appears to have existed in the pre-Hispanic period as well, as the text associated with the weaving scenes in the almanac on page 102b of the Madrid Codex (see Fig. 7) refers to the weaving as the goddess' *y-al*, meaning "her child."

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Clovis Blade Manufacture

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C

Introduction

During the last glacial stage (ca. 11,000 BCE), Clovis people introduced from Eurasia into the New World a culture reflective of their Paleolithic homelands. Archaeological evidence indicates that these cold-adapted groups employed "hard" technologies for making lithic and osseous utensils and "soft" technologies for textiles, basketry, and cordage (Bradley, Collins, & Hemmings, 2010). Animal remains and environmental information at some sites, combined with artifacts, suggest that Clovis people were organized into egalitarian nuclear families and bands; that they followed a nomadic lifestyle, which included hunting mammoth and other large game; and that they gathered wild foods seasonally (Boldurian & Cotter, 1999; Neusius & Gross, 2013). While it is likely that generally poor organic preservation at sites exaggerates the importance of lithic tools in Clovis culture, the finely flaked projectiles known as fluted points, grooved and edge-polished along the base, are found across all of North America (Fig. 1). Like fluted points which unmistakably signify Clovis, other stone tools of superior flintworking – prismatic blades – firmly demonstrate the Old World ancestry of Clovis and may be another diagnostic component of this ancient culture (Collins, 1999).

Tools of Choice

Prismatic blades served a variety of functions in antiquity, such as cutting, scraping, scoring, perforating, and shaving. Like utility knives of today, blades were superlative kitchen and household utensils. With long, sweeping edges, blades

were either held by hand or attached to a handle, to perform more efficiently. Though of delicate appearance, blades were surprisingly strong and of high tensile capacity, which enabled them to resist snapping under heavy force (Collins, 1999). Blades were robust and durable and withstood repeated repair. Whether new or well worn, blades were versatile and served as stock for making brand new tools. These next-generation utensils served in an array of domestic tasks, including scraping hides, planing and shaping wood, shredding plant fiber, scaling fish, and scoring and perforating leather, as well as etching and drilling bone and antler (Boldurian & Hoffman, 2009). The fact that blades were readily recycled into new forms immensely extended their importance in ancient toolkits (Fig. 2).

Clovis Blade Manufacture, Fig. 1 Clovis fluted projectile points. Scale is in cm

Making Clovis Blades

Manufacturing Clovis prismatic blades required much knowledge and skill. Yet the highly complicated procedure was unpredictable and, even for the best artisans, sometimes went awry (Bordes & Crabtree, 1969). Thus, the following description implies an ideal, error-free progression that was not always the case. To procure suitable stone, flintworkers searched outcrops for roughly head-sized masses of flint of sub-cubical to spherical shape (Fig. 3). Also, nodules were tested for purity in silica content and absence of internal flaws. Experienced artisans determined these qualities by removing just a few flakes. Next, a suitable nodule was carefully formed into a designated shape, which prepared it for detachment of prismatic blades. This stage entailed making a striking platform and building a guide ridge, after which the mass of stone could be called a "core." A blademaker's toolkit, including hammerstones and antler utensils, is depicted in Fig. 4.

Clovis Blade Manufacture, Fig. 2 Clovis blades fashioned into formal tool types. *Left*-to-*right*: combination side-end scraper, backed knife, end scraper, combination graver-end scraper, and combination knife-side scraper. Scale is in cm

- **Striking Platform**

  Cleaving a large portion from one end of the nodule created a flat surface, which served as a stage to receive force for each blade removal. This broad area could last for the entire blademaking procedure (Fig. 5).
- **Guide Ridge**

  On nodules that had a rounded, featureless surface, it was essential to create a ridge. This prominence guided force from the striking platform so that the first blade could be detached and allowed force to propagate farther along the core's main axis, which yielded the longest blade possible. To create this ridge, alternate flaking along one side formed an elongated area raised above the rest of the stone's mass. If the nodule had a natural ridge, then building a guide ridge was unnecessary.

The first blade to be removed was the crested blade defined by the guide ridge. Its removal left two parallel ridges on the core, each of which was formed by the lateral margins of the crested blade as it detached. These ridges guided detachment of additional blades. Each new blade was removed via force applied to the striking platform at the proper angle, directly behind a ridge. At this advanced stage in manufacture, the prepared core looked like a truncated cone with many flat facets and is termed by archaeologists a polyhedral core. Two techniques for detaching Clovis blades from a polyhedral core have been proposed: direct percussion and indirect percussion.

Clovis Blade Manufacture, Fig. 3 Procurement of unmodified stone. Note its weathered exterior or cortex

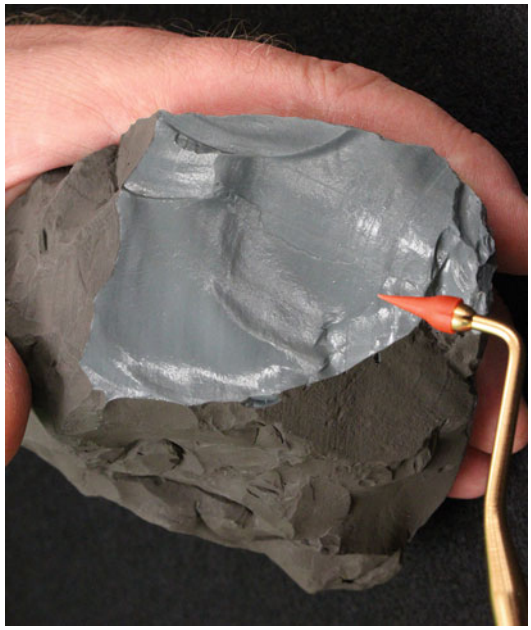
- **Direct Percussion**

  With one hand holding either a hammerstone or an antler billet [a soft hammer], the artisan applied force directly to the core's striking platform. In the other hand, he held the core, either freely or resting it upon his lap (Fig. 6a, b).
- **Indirect Percussion**

  Two flintworking tools were employed, an antler hammer and a punch. At its distal end, the punch had a blunted tip, which was placed at the point on the striking platform and at the precise angle where force was desired. Force

Clovis Blade Manufacture, Fig. 4 A contemporary blademaker's toolkit. Utensils include hammerstones, antler punches (*left*), antler hammer (*center*), and antler billets (*right*)

traveled from the hammer to the core via the intermediary punch. To facilitate this manner of delivering force, the core was braced in one of three positions: (1) unsupported at the bottom and gripped between a seated artisan's knees; (2) with the core at rest on the ground, secured under one knee; or (3) again supported from below, held between both feet (Fig. 7a, b).

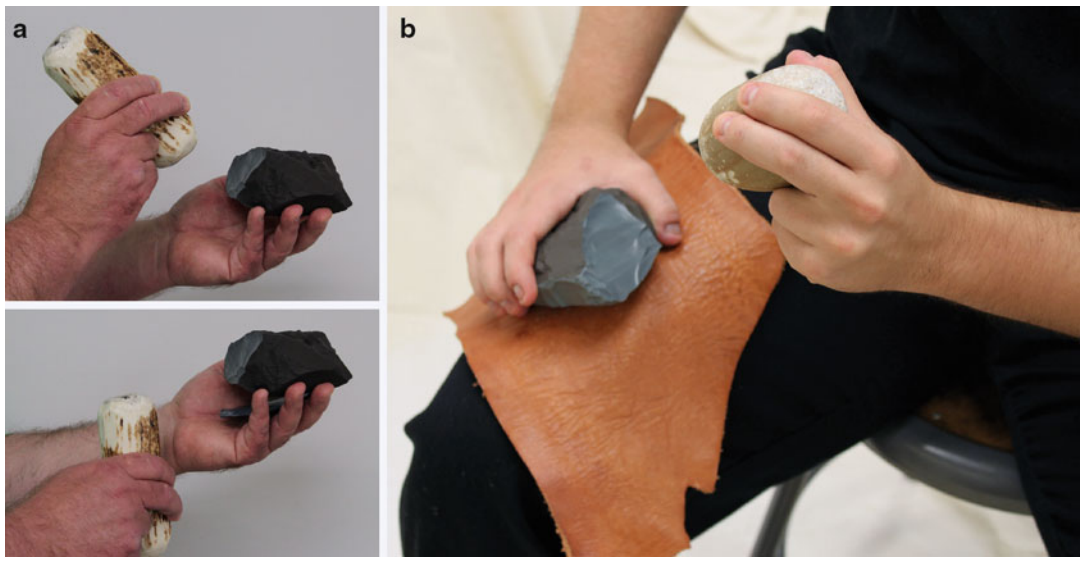


Clovis Blade Manufacture, Fig. 5 Making a striking platform

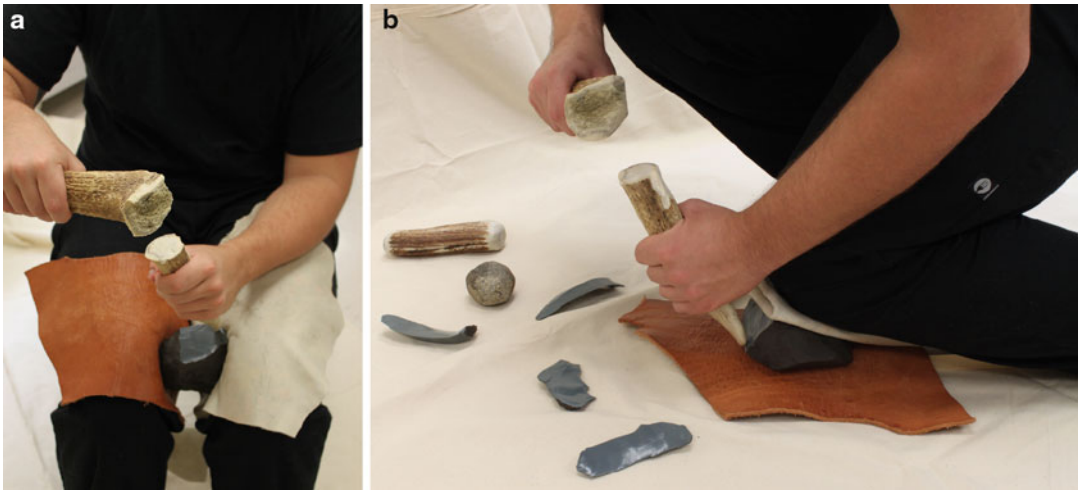
In repetitive sequence, blades were then detached from the prepared core (Figs. 7b and 8). Each time, force was directed onto the striking platform directly behind a guide ridge, thereby ensuring an unimpeded flow of force that was needed to remove a blade (Fig. 9).

Blade Morphology and Landmarks

Prismatic blades are long, narrow, and thin. On the dorsal surface, they have at least one ridge as evidence of prior blade removals. Blades with one ridge are triangular in cross section; those with two ridges are trapezoidal. These features of blades – elongate and slim with a three- or four-sided sectional shape – explain why they are commonly called *prismatic* (Bordes & Crabtree, 1969; Crabtree, 1972). At the proximal end, Clovis blades retain only a tiny remnant of



Clovis Blade Manufacture, Fig. 6 (**a**) Making prismatic blades via direct percussion using an antler billet. Image depicts moment prior to blade detachment (*top*) and immediately afterwards (*bottom*). In both images, note how the core is cradled in the flintworker's hand. Blade detaches into the palm. (**b**) Making prismatic blades via direct percussion, using the lap to rest the core

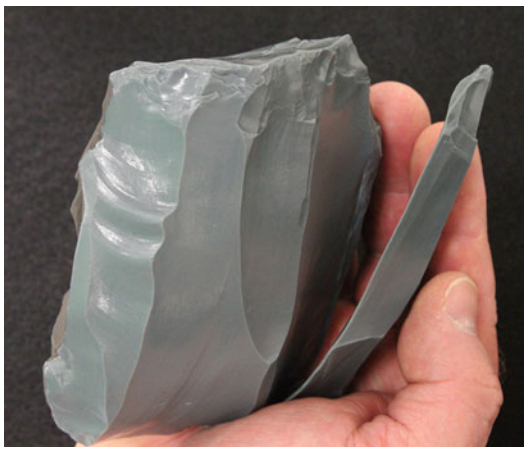


Clovis Blade Manufacture, Fig. 7 (**a**) Making prismatic blades via indirect percussion with an antler hammer and punch, using the knees to brace the core. (**b**) Making prismatic blades via indirect percussion with an antler hammer and punch, using the knee and a rest to brace the core

Clovis Blade Manufacture, Fig. 8 Replica Clovis blade core and prismatic blades

the core's striking platform. Blades made by other prehistoric peoples usually have much larger platform remnants (Collins, 1999). The ability to take only a diminutive platform was enabled by preparation to the point of detachment immediately prior to force application. Scars from this preparation appear at the blade's proximal end. These features of Clovis blades reveal great skill in the process of detaching blades while sacrificing only the smallest amount of the striking platform. Interior surfaces of Clovis blades typically are smooth and free of undulations. Though in shape and design very similar to Old World Upper Paleolithic blades (Fig. 10a), Clovis blades differ in that they usually curve inward near the distal end (Fig. 10b). On the ventral surface near the proximal end of Clovis blades, the bulb of force is typically slight or diffuse, suggesting that force was delivered by a soft hammer such as a billet, instead of a dense, stone hammer. Collectively, these features, depicted in Fig. 11a–e, indicate the Clovis artisan's intimate knowledge of flint and reflect his ability to manage its physical properties (Collins, 1999).

Newly manufactured Clovis blades are usually 10–20 cm (4–8 in.) in length and rarely exceed 5 cm (2 in.) in width (Fig. 12). Lithic analysts measure many linear dimensions of blades and ascertain myriad conditions of blade morphology (Boldurian & Hoffman, 2009; Meltzer & Cooper, 2006).

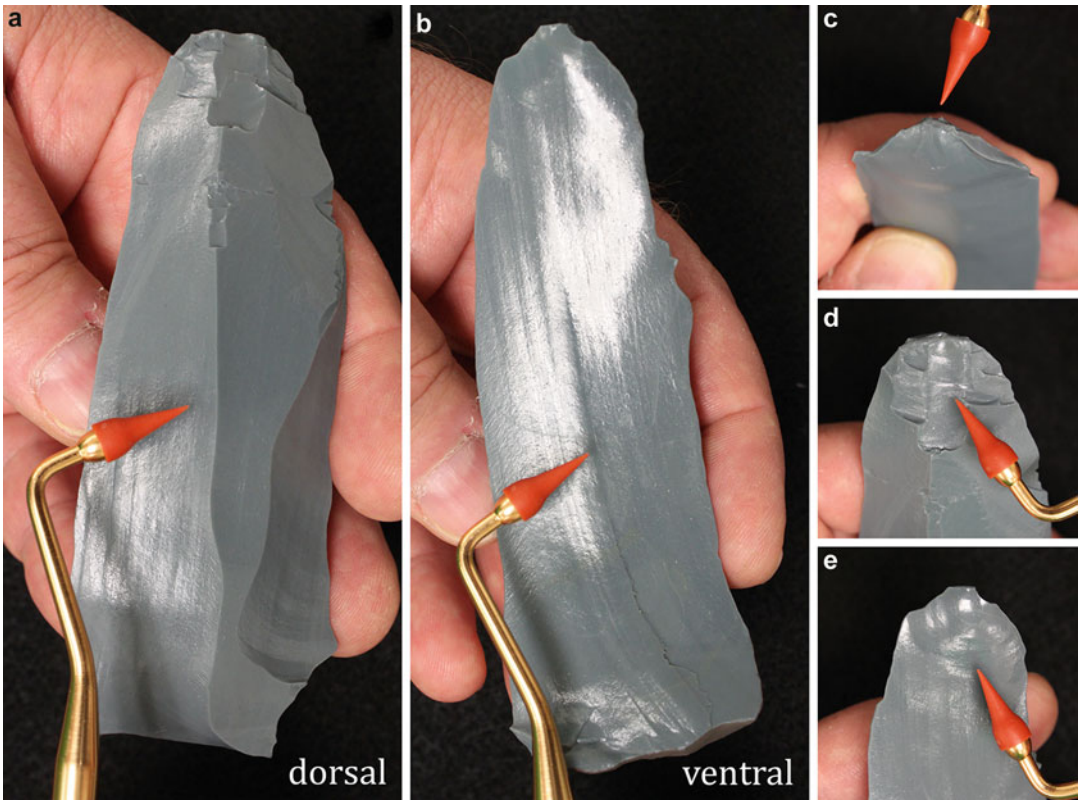


Clovis Blade Manufacture, Fig. 9 Replica Clovis prismatic blade detaching from prepared core

Uncertainties, Issues, and Debates

After 50 years, issues and debates over the entire manufacturing process of Clovis prismatic blades continue (Hammatt, 1970; Montgomery & Dickenson, 1992; Stoltman, 1971; Warnica, 1966). Uncertainties exist regarding whether Clovis artisans routinely employed direct percussion or, alternatively, indirect percussion in the blademaking procedure (Bordes & Crabtree, 1969; Crabtree, 1972; Newcomer, 1975). An intriguing feature of Clovis blade manufacture is the curvature of blades, which regularly does not appear in Eurasian Upper Paleolithic counterparts (Collins, 1999). Finally, there are questions about the distinctive character of Clovis blades. Since Clovis groups were not the only prehistoric peoples of the New World to make blades, to what extent are certain blades in their overall shape and design indicative of "Clovis" (Bradley et al., 2010; Collins, 1999; Haag, Bergman, & Carr, 2014)? Like fluted points, may prismatic blades be considered diagnostic artifacts of Clovis culture? Only the briefest answers to these questions are offered here.

Clovis Blade Manufacture, Fig. 10 (**a**) European Upper Paleolithic prismatic blade. (**b**) Lateral view of European Upper Paleolithic blade (*left*) and Clovis blade (*right*). Note differences in curvature



Clovis Blade Manufacture, Fig. 11 Landmarks of Clovis prismatic blades: (**a**) dorsal surface with ridge separating parallel negative flake scars; (**b**) ventral surface with smooth, inward curving interior; (**c**) tiny platform remnant at proximal end; (**d**) platform preparation flake scars; (**e**) slight bulb of force on ventral surface

Prismatic blades bearing virtually all the features of Clovis blades have been manufactured by contemporary flintworkers using both direct percussion and indirect percussion (Boldurian & Hoffman, 2009; Bordes & Crabtree, 1969; Collins, 1999; Newcomer, 1975). Elongate, thin blades with tiny platform remnants, diffuse bulbs of force, smooth interiors, and curvatures like those of Clovis blades have been manufactured in independent studies using both techniques. Pronounced curvature in experimentally produced blades occurs most frequently when the prepared core is either cradled in the hand during direct percussion or stabilized between the knees or feet during indirect percussion. In each of these scenarios, the core rolls slightly due to applied force during blade detachment. This forward movement may explain why Clovis blades are frequently curved (Boldurian & Hoffman, 2009).

The archaeological value of Clovis blades as diagnostic artifacts is an open question (Bradley et al., 2010; Gramly, 2013; Green, 1963; Haag et al., 2014; Meltzer & Cooper, 2006). Some analysts believe that the ensemble of features which typify Clovis blades is sufficient to render them as truly diagnostic (Collins, 1999). Others caution that, whereas this may be so, blades – unlike fluted points – are often absent from Clovis sites and, therefore, are an unsuitable spot test for Clovis. Still, when prismatic blades occur in Clovis assemblages, they are easily identified from those of other cultures (Collins, Hudler, & Black, 2003; Ellerbusch, 2004;

Clovis Blade Manufacture, Fig. 12 Clovis prismatic blade, dorsal view. Scale is in cm

Tunnell, 1978). Further research on prismatic blade manufacture is sorely needed, all of which will stimulate additional lively discussions among archaeologists as they strive for a deeper understanding of America's Ice Age Clovis culture.

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Coir in India: History of Technology

K. T. Rammohan

Coir, a natural fibre used extensively to make brush, spin yarn, twist rope, and weave carpets, is obtained from coconut. The coconut tree (*Cocus nucifera*) grows in many tropical countries but chiefly in India, Thailand, Sri Lanka and the Philippines. Within India it grows best on the southwest coast of Malabar, especially in the state of Kerala. Europeans and Arabs used to refer to it as the Indian Nut. One of the earliest references to its production in Kerala appears in a temple inscription of tenth century, which refers to the fruit as *tengai* and lists it as a major source of revenue to the temple. *Ten* means the south, probably indicating its arrival from South Sea Islands and/or Sri Lanka by the sea. While there is inscriptional evidence of coconut groves from this period, really large-scale cultivation – turning almost the whole region into a vast coconut grove – begins from the sixteenth century. For the people of Kerala, the coconut tree is what the reindeer is to the Eskimos; it fulfils many needs.

The coconut tree with its long trunk – very rarely branched – stands tall on sandy tracts adjoining the sea and backwaters. It yields fruits – coconuts – about three-quarters the size of a football. These are green on the outside when tender, turning into brown as the coconut ripens. Coconuts are usually plucked by a male worker climbing up the tree using a loop grip-chord at the ankles. Sometimes, to ease labour, a single ► bamboo (*Dendrocalamus strictus* or 'male bamboo') is leaned against the tree and used to gain the first long ascent from the ground – the branches extending from the nodes of the bamboo serving as steps – while the rest of the climb is completed using the loop grip-chord. On reaching the top, the climber cuts off bunches of coconuts with a knife and drops these to the ground. The nuts are picked from the ground, collected and carried in bamboo and reed baskets, mostly by women.

Only male workers of specific castes group engage in plucking coconuts. Usually they do not take up other work. The collecting women could be of any caste and are not restricted solely to this activity. Even today the wages of the climber and the collectors are paid partly in coconut. Over the past two decades semi-mechanical devices for tree climbing have been introduced but these have not gained popularity as experienced climbers do the job much faster.

A hard shell with an outer cover of fibrous mass protects the coconut kernel. The coconut is first removed of its husk with an iron spike or a knife. To obtain the kernel the inner shell is cracked, yielding two, fairly hemispherical pieces, brown on the outside and white inside. The coconut kernel is an important component of the everyday diet of the people of Kerala and is their chief source of oil for cooking and anointment. It is the coconut husk obtained while cutting up the coconut for kernel that yields fibre. Coir is thus the product of a by-product obtained in coconut cultivation.

Yet, of the several industries associated with the coconut tree in Kerala, the coir industry is the most important in terms of employment and investment. The use of Malabar coir yarn and rope for maritime purposes internationally has a history that may be traced to the thirteenth century or even earlier. Coir yarn was used to stitch together the planks of a ship and ropes were used to tie the sails to the mast. Coir ropes were also used in fishing. Weaving of coir matting or carpets on the Malabar Coast dates back to the nineteenth century. For the poor in Europe, coir matting substituted for expensive carpets, while for the rich it served as an underlay for expensive carpets. Coir fibre was used in upholstery and in making brush mats. While coir yarn was widely

used locally for agricultural purposes, mat and matting were woven primarily for the world market.

Initially, coir fibre and yarn were exported from Kerala to Great Britain where these were woven into brush mat and matting. As coir fibre is bulky, transport over long distances was uneconomical. Baling presses could not gain wide acceptance because baled fibre was hard to tease. From the mid-nineteenth century, carpet weaving factories were set up in Kerala's port towns, initially under the initiative of British capital and subsequently by local entrepreneurs – although export of fibre and yarn and its processing elsewhere continued. The expansion of the coir matting industry and the consequent rise in demand for raw material yarn prompted changes in the scale and technology of spinning. Unlike weaving, which was conducted in factories spinning was household production. It continues to be so even today.

To produce fibre, the coconut husks are first treated in saline water (retting) and the fibrous mass removed from its semi-hard shell by hand (ripping). That is beaten with a rod to yield tufts of fibre (defibering), and finally cleaned by throwing up in the air. The husks are carried by big, country canoes along canals to the backwater for saline water soaking. To soak the husk, a big, circular net of coir is stretched across the water surface and stacked with husks. A worker standing on the backwater bank throws husks into the net. Workers standing waist-deep in the backwater arrange the husks in layers, one over another, in the net. Usually, 10,000 husks are stacked in a net. The stacked husks are covered with plaited coconut leaves and tied together on the top, crisscrossed with coir strings. The husk mass is then punted to the interior of the backwater and covered with mud and stones dug out from the backwater bed. The plaited coconut leaf cover and mud ensure that the husks do not dry up in the sun. As the husks absorb water, since they are burdened with heavy stones, the husk mass sinks a little. To distinguish between husk mass sunk by different owners, small metal discs bearing the initials of the owner or a number code are inserted into the husk mass.

The husk mass remains in water for a period ranging from 6 to 8 months or even more. Flushing washes away tannin and facilitates bacterial action that decomposes the fibre-binding pectin. Salinity lends strength to the fibre. The husk mass becomes heavy after retting and has to be brought back to the backwater bank in a canoe. Workers standing waist-deep in the backwater untie the retted husk mass and throw the husks into the canoe. The retted husks are unloaded at the defibering sites that are usually located on the bank. Women workers carry these as head load to the work spot. Male workers, usually drawn from subordinate caste groups, do the entire retting operation.

In certain parts of Kerala retting is carried out by burying the husks under the beach sand. Retting in small ponds in the homestead is also in vogue. Unlike backwater retting, which is a male preserve, women undertake retting in beach sand and ponds. The defibering mills that have been built in the past few years do away with the retting operation and defiber the green husks. The fibre so produced has to be soaked for a few days in saline water later. Even then, its quality is inferior to that produced by retting (Figs. 1 and 2).

Defibering or separating fibre from the retted husk is done entirely by women, mostly of subordinate caste groups. The worker squats on the ground and rips off with her hand the loosened fibrous mass from its semi-hard shell. She then places the fibrous mass on a flat stone or wood and gently beats it with a small iron or metallic rod. A few beatings and the black, retted husk turns into a tuft of golden brown fibre.

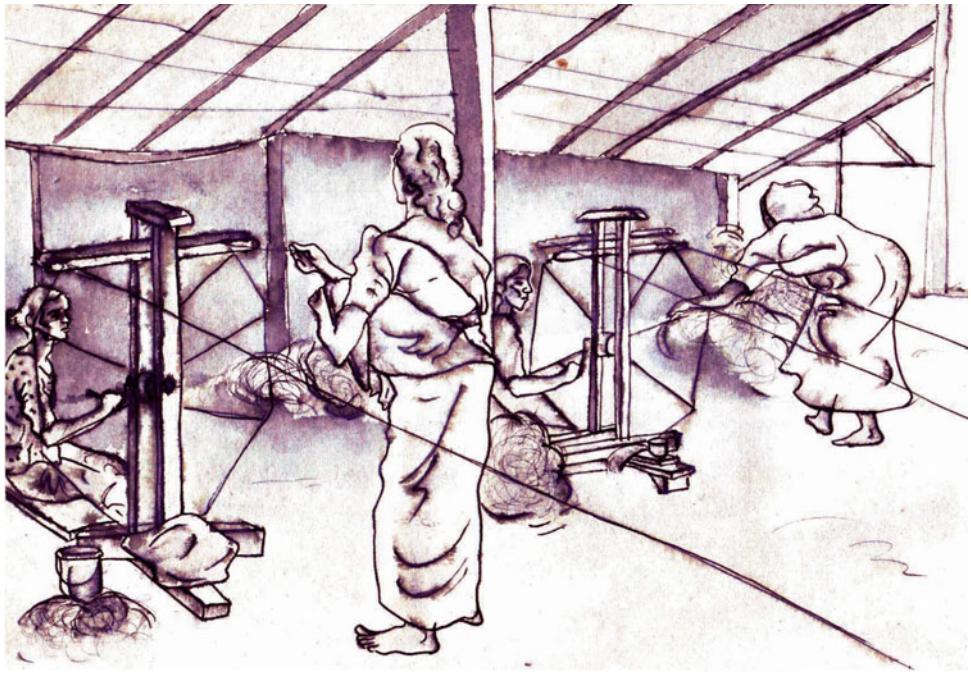
A large quantity of fibre dust or pith is produced in defibering. Accumulated pith makes small hills on the backwater side. This is occasionally removed and used as a saline input or as ash in coconut groves and vegetable gardens. More recently pith has been put to new uses. It is baled into pith bricks for use in indoor gardening or into pith logs to block soil erosion. Like other coir products these also enjoy global demand.

Coir in India: History of Technology, Fig. 1 Retting

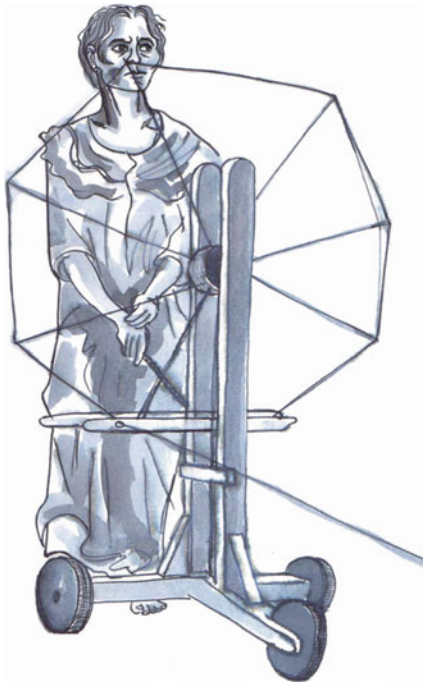
Coir in India: History of Technology, Fig. 2 Defibering

Defibering work is backbreaking. The long working hours, continuous exposure to sun and rain, the uncomfortable squatting posture, contact with fibre particles and dust, and lack of a balanced diet because of the very low wages often cause women's health to deteriorate. There had been attempts to mechanise the defibering operation beginning from the nineteenth century, but these were given up as employing labour was cheaper and capable of producing better quality fibre as compared to the mechanical process. Attempts at mechanisation occurring in the latter half of the twentieth century were defeated by workers who were faced with the threat of unemployment. Over the past decade, however, defibering mills that can process large quantities of raw husks have been established (Figs. 3 and 4).

As with defibering, only women workers and mostly of subordinate castes spin coir yarn. Traditionally the fibre was spun into yarn by rolling between the palms. With the expansion in international demand for coir carpets and therefore for yarn for weaving in the



Coir in India: History of Technology, Fig. 3 Spinning



Coir in India: History of Technology, Fig. 4

mid-nineteenth century, spinning wheels were introduced. A woman worker – most often a child or an old woman – rotates the fixed wheel while two other women workers walk backwards feeding fibre and drawing out a strand of yarn. The workers then walk forward, twisting the two strands into one by pushing a moveable wheel and by running a triangular wedge. The spun yarn is counted and bundled and delivered in the market or sent to the weaving site by country canoes, carts, and trucks.

Spinning is laborious. By the end of the workday, a spinner, walking forward and backward between the two spinning wheels, would have covered a distance of about 8 km. The spinners often tend to develop body disorders, especially the outward curving of their feet from walking backwards. For centuries, the low wages of spinners has been a disincentive to entrepreneurs in experimenting with mechanised processes. During the past decade, coir workers' cooperatives have sought to increase productivity and reduce labour

by introducing electrically operated spinning wheels. These have not been very successful. The yarn tends to break too often in mechanised spinning and the final output is not of a quality that matches the yarn spun on hand-rotated wheels.

Spinning yarn by rolling it between the palms still continues in parts of Kerala. Rope making is also done by hand. One end of the yarn is tied to a coconut tree and the other end passed through the eye of a coconut shell. A small stick is then tied to the other end and briskly rotated. This draws the yarn and gives it a hard twist. After toughening each yarn, these are plaited to make rope. Depending on the strength required, four or more yarns may be plaited.

Certain kinds of coir yarn are used in agriculture, packing, and house construction. Certain other kinds are raw material for weaving carpets. Traditionally, entirely and even today, mostly, coir yarn is woven into matting on wooden handlooms. In contrast with defibering and spinning done only by women, weaving is exclusively male labour. While a mat is woven on relatively small looms worked by a single worker, matting is made in large looms with six to eight persons working in unison. Power looms have led to a substantial rise in productivity and a widened range of products – sometimes in combination with jute and latex – but some of the designs may be worked only on handlooms.

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Colonialism and Medicine in the Malay Peninsula

Hairudin Bin Harun

The history of British medicine in the Malay Peninsula is synonymous with the history of tropical medicine. It is also a history of colonial medicine, which is a chapter of the history of British colonialism and imperialism in the East.

Three factors were crucial in determining the outcome of the struggles by colonial powers to expand and consolidate their empires in the East: sea-power, colonial settlers, and diseases. The nation that controlled the sea could occupy distant lands with ease. If there were conflict, sea-power enabled a colonial nation to intercept and prevent vital supplies from reaching rival colonies. Colonial settlers were important for political and economic reasons. A claim for the motherland could easily be made over an area well settled with colonial immigrants. Economic exploitation and control could be established by a network of colonial settlements, which also functioned as buffers against economic challenge and security threats from natives or rival powers. Finally, disease was of immense importance in moderating colonial expansion. Diseases could exact a heavy toll on the army, officials, colonial settlers, and their laborers or slaves. Malaria and yellow fever reportedly wiped out some of the British colonies in the tropics and Africa.

British colonial rule over the Malay Peninsula and Borneo Island (now Malaysia) lasted for more than a century. Their use of medicine as a strategic, diplomatic, and political tool to enhance their grip on the indigenous people and resources of the Malay Peninsula is well-documented. Medicine was also an instrument of colonial conscience, one aspect of which was the call to discharge "the white man's burden," including the task of "civilizing" the natives. In the Peninsula this entailed, among other things, the aggressive promotion of tropical medicine, and it contributed to Malayan negative perceptions of colonial medicine. Indeed, colonial medicine came to be perceived as a ruthless campaign to stamp out their traditional medicine.

In spite of that, colonial medicine could still claim success among the colonial laborers and urban dwellers, although among the natives and villagers the campaign seemed to have failed. There are several reasons for this. One was the preexistence of an elaborate traditional medical system. Second, the natives enjoyed better health than the imported colonial laborers, and even the colonial masters, many of whom were afflicted either with beriberi or malaria. Third, local traditional medicine was far more effective in treating some forms of tropical diseases.

The effectiveness of Malay medicine, however, was generally overlooked. It was difficult for colonials to accept that a primitive medical tradition could be equal to or better than colonial medicine. The official attitude further institutionalized such prejudices, as Malay medicine was officially perceived with contempt.

Since the beginning of British colonialism in the Malay Peninsula, combating tropical diseases was a priority. Initially, it was important to the officials and indentured colonial laborers, and it assumed a strategic and political dimension.

If one were to put a date on the genesis of British colonialism in the Malay Peninsula, it is likely to be 1786. This was when the East India Company took possession of Penang from the Sultan of Kedah. By 1830 the Company had added Singapore and Malacca to its inventory list, and by 1895, four of the richest Malay states in the Peninsula were under British influence. Throughout the period, the number of Britons sent to the area increased tremendously. The Peninsula's climate and geography, however, were harsh, and many of the early colonialists succumbed either to the heat or diseases. The large-scale importation of foreign indentured laborers, known then as *coolies*, was a significant feature of the period. They were crucial for economic and political reasons, but they were also decimated by diseases, especially malaria and beriberi. The result was a loss of productivity and a forced suspension of many economic projects. Thus, disease, or its absence, among

officials, settlers, and coolies acquired an economic imperative; while health or the lack of it among natives acquired a strategic and political dimension.

During the colonial period, the course of events in the Peninsula was inevitably intertwined with that in England. The 1870s saw the emergence of a new political figure in Britain, Joseph Chamberlain (1836–1914). In 1893 he was appointed Secretary of State for the Colonies. He reorganized the Office from an ill-equipped, almost forgotten, department to one of the best around. Indeed, colonial appointments before he took office were seen as more akin to polite exile than glamorous jobs. Chamberlain changed that. He was able to infuse a new attitude, as well as a new policy, so that the colonial jobs gained the same respectability as home appointments.

As far as the history of colonial medicine is concerned, Chamberlain's most significant political act was his appointment of Dr Patrick Manson (1844–1922) as the Medical Advisor to the Colonial Office. Dr Manson was then the most distinguished authority in tropical medicine, which was then a marginal subject within mainstream medicine. The main concern of British medicine was the diseases of Europe, not of the tropics, and health policy was geared to serve home needs and rarely those of the colonies. Under Chamberlain, with Manson as the medical advisor, there was a reorientation of policy and priorities. The medical problems and health policies of the colonies were given serious attention. Soon Chamberlain's name became synonymous not only with the development of British colonialism but also with the development of tropical medicine. Indeed, under his stewardship, Britain's colonial fortune took a positive turn; so too did the health of Britons and the state of medicine in the colonies.

Chamberlain was forthright about the fact that British lives were more important to him than native lives. The participation of his ministry in the development of British tropical medicine was solely to ensure their welfare. The welfare of the natives was looked upon only in terms of Britain colonial interests, if ever. This policy was reflected in the establishment of the London School of Tropical Medicine in 1899. Its purpose was to foster research and development of the "new" British tropical medicine. The school was backed up by a number of research stations in the colonies, the biggest and most important of which was the Kuala Lumpur Pathological Institute, located in the Federated Malay States (British Malaya). The Institute was formed a year after the London School. Indeed, the rapid development of British tropical medicine in the early part of the century owed much to the linkages of the London School with the Kuala Lumpur Institute.

The Institute's founder was Sir Frank Swettenham (1851–1945), a charismatic colonial official who knew a lot about colonial and local politics but next to nothing about medicine. Swettenham's tenure coincided with the period of intensive colonial economic activities in the Malay States. These were sustained mainly by the extensive importation of coolies from abroad, particularly from China and India. As indicated earlier, this importation was important for both economic and political reasons. It showed the native Malays that the British could easily handle any boycott by local labor; but the importation soon hit a snag. Many of them were decimated by unknown diseases, one of which was later identified as beriberi.

Owing to the epidemic, the local colonial administration was burdened by thousands of sickly and unproductive coolies. A search for a beriberi cure was imperative. Swettenham had come to know about the interest at the Colonial Office regarding tropical diseases, and about the plan to set up a school of tropical medicine in London, but he also knew that the School's priority was research on tropical diseases afflicting European communities in the tropics. In the Peninsula, however, beriberi was a non-European disease. Swettenham was aware that it was extremely difficult, if not impossible, to persuade the Colonial Office to allow it to devote a portion of its research time and money to beriberi. It was at this stage that he toyed with the idea of a local institution modeled after the school, which would facilitate the search for beriberi's cure.

In London, luck seemed to be on his side. Swettenham's plan for a local medical research institute was received positively. It was seen as simply the compliance of a colonial official to London's policy on tropical medicine. Such plans from distant colonies normally received an impersonal go-ahead signed routinely by nameless individuals on behalf of the Secretary. Instead, Swettenham's plan came to the attention of Chamberlain, who personally signed the authorization papers for the Institute. At home, Swettenham did not bother to wait for the official go-ahead; he had made arrangements to set up the Institute even before Chamberlain had signed the order.

Perhaps owing to the excellent staff, the Institute lived up to its expectation. It was able to come up with the cure for several tropical diseases, including beriberi. The riddle to the latter was conclusively resolved exactly 9 years after the founding of the Institute. Thus it succeeded in alleviating the colonial authorities from one of the major causes of the local economic and social problems. The Institute was a bastion of colonial medicine, and far removed from the practices of traditional medicine. Notwithstanding that, some of the major breakthroughs of the Institute were affected directly or indirectly by the latter. For instance, in the search for the cure of beriberi the Institute's scientists looked to traditional cures for clues, and indeed found a lead in Malay medical practices. Colonial pharmacologists examined and benefited greatly from the Malay materia medica, particularly in the search for new drugs and alkaloids. Institute authorities still were extremely reluctant to acknowledge any hint of contribution by native medicine, especially in advancing tropical medicine.

To understand the events that followed, it is necessary to take a brief look at the prevailing colonial health policy, particularly with regard to the natives. There were several discernible phases. The initial phase placed the emphasis on the health of the officials and laborers with no regard to the natives. The second phase involved the missionary zeal to promote colonial medicine among the natives and other non-European inhabitants of the colonies. The *Ordinance to Provide for the Registration of Medical Practitioners in the Colony* (1905) was passed to control the practice of medicine, by stipulating minimum qualifications for those who wanted to practice medicine in the Malay States. On the face of it, the Ordinance seemed to spell a blow to traditional medical practitioners, particularly the natives and the Chinese, but interestingly, the Ordinance carried with it an exclusion clause:

> Nothing contained in this Ordinance shall be construed to prohibit or prevent the practice of *native* systems of therapeutics according to Indian, Chinese or other Asiatic method.

Throughout the British rule the native Malays relied extensively on traditional medical systems for their medical needs. The backbone of the traditional system was the medicine man, *bomor*, or *pawang*. They did almost everything, from preparing herbal medicines, setting dislocated bones, and delivering babies, to variolation and minor surgery like circumcision. Occasionally, Europeans sought treatment from the *bomor* and claimed that they were cured of their ailments by the Malay medicine man.

Evidently, colonial medical officials were intrigued by the ability of the native Malays to live a healthy life in the tropical climate. Many noticed that the native Malay view of nature was totally different from theirs. Nature or the land was treated by the Malays with respect, regarded more as a living or spiritual being than a thing, and more like a member of their family than an artifact of convenience. The Malays maintained a relationship with their land in what one would describe now as balanced ecological relationship. In fact, the need to seek harmony and equilibrium was central to their view of disease and health. Nature was multidimensional and hierarchical, having both a metaphysical and physical dimension – reflecting the spiritual and physical constitution of man. Their doctrine of diseases and health reflected the belief that health was a manifestation of the harmony of human's inner constitution and nature's constitution; disease was the result of a lack of harmony.

The complexities and intricacies of the Malay medical doctrines were left much to themselves.

Occasionally they became objects of anthropological curiosity by colonial scholars. However, this attention was academic; no medical officials or policy makers seemed interested in knowing more about Malay medicine or the Malay medical system. It was not until the later stage, the missionary zeal phase, that they began to take notice of Malay medicine. At this stage, however, Malay medicine was seen more as a rival than a complement.

The effort to introduce colonial medicine to the Malays was apparently a frustrating task to the majority of the colonial officials. Frequently, they expressed their frustrations at what they alleged was the Malays' indifference to "superior medical treatments." For instance, the Colonial Resident Councillor of a Malay State remarked:

> If a Malay thinks he is going to be kept in a hospital, he will not apply for medicine as an outdoor patient and will prefer to remain in his own house and be treated by a Malay doctor on simple herbs, together with a judicious supply of still simpler incantations. (Harun, 1989a)

The Colonial authorities also took active steps to restrict the practice of Malay medicine men. This perhaps can be best seen in the checking of the traditional inoculation or variolation practice. Variolation was widely practiced whenever smallpox broke out in a village. It involved the direct inoculation of smallpox virus treated with certain medicinal herbs. Colonial doctors described it as "a barbarous practice," and the practice was targeted for curtailment. In 1905, when smallpox broke out in the eastern Malay state of Kelantan, the Government enforced a law banning variolations. In their place, they introduced large-scale vaccinations. The authorities also recruited some traditional inoculators as "assistant vaccinators," although the actual task of vaccination was undertaken by the colonial medical department.

To the Malays, the inoculation rituals sanctioned by their traditional culture were much preferable to vaccination. Their acceptance of colonial medicine lagged behind official expectation. In fact, the authorities noted a decrease in the number of natives seeking medical treatment at colonial clinics. They realized that the campaign to promote colonial medicine among the Malays would fail unless their confidence was won over.

The new campaign strategy perhaps can be best seen in the work of Dr Gimlette. He was a colonial medical officer best known for his sympathetic and detailed study of Malay medicine which was originally part of the new campaign. By the time he finished, it had taken an unexpected form. For all practical purposes, it had become a crusade for the preservation of Malay medicine. Gimlette, probably to the displeasure of his superiors, openly urged the colonial authorities to soften their attitudes toward the *bomors*. Indeed he argued that "it would be unfair to damn him [the *bomor*] as an accursed sorcerer who poisons honest folk to gain his private ends." Gimlette even drew parallels between the practice of colonial doctors and that of the medicine man:

> It is too much to say that the work of the bomor in clinical medicine is merely fanciful; he endeavors to prepare a *penawar*, that is to say a "neutraliser," for every kind of poisonous principle; this idea of neutralization distinctly anticipates modern science. His knowledge of local materia medica is often profound, and after all, some of his theories as to the etiology of tropical diseases are conceptions now known to modern science in the form of animal parasites (protozoa, spirochaetes, etc.), which are invisible except under high powers of microscope.

Gimlette also claimed that Malays knew mosquitoes were the cause of malaria, evidently earlier than Manson. According to Gimlette, Malays' apparent resistance to malaria was largely owing to their knowledge of mosquitoes. For instance, the Malay traditional ritual of smoking their homes and villages through the burning of *padi* (paddy) straw during harvest season effectively expelled mosquitoes in their homes or in the surrounding area. Malays also bred fish in their *padi* fields during the flooding period. This practice was akin to a form of biological control of pests, since the fish preyed on small organisms and thus destroyed all the mosquito larvae breeding in the *padi* fields. The Malays also practiced selective clearing of

jungles as another form of mosquito control. Gimlette was convinced that the secret of Malays' resistance to malaria or "harmony" with mosquitoes, lay in their practice of such rituals.

It is not known what the actual reaction to Gimlette's views was, particularly within the colonial medical establishment. It is likely that his views would have caused some uneasiness among officialdom. Gimlette assigned a common level of legitimacy to Malay medicine and colonial medicine. It is interesting to note that soon after the publication of his book on *Malay* Poison, Gimlette retired in 1921 from the Colonial medical service. He returned to England and embarked on a project to compile a dictionary of Malay folk medicine. Because of ill health, the project was not completed. However, his friends, Thomson and Skeat, took over the project and completed the manuscript, which was posthumously published in 1934 as the *Dictionary of Malayan Medicine*.

The official version of the development of colonial or tropical medicine was no different from the history of medicine. The motives were Hippocratic idealism and the fanatical dictum that there should be no mention of nonscientific or nonmodern contributions to the development of modern medicine. Understandably, the Malay's contribution to the development of colonial medicine in the Peninsula was largely ignored.

The prevailing colonial view stereotyped native medicine as nothing more than primitive panaceas or "snake-oil cures." However, studies like Dr Gimlette's challenged established prejudices and institutionalized misconceptions. They established that native medicine was a storehouse of perennial wisdom, and collection of empirical observations of scientific significance. Still, Malay medicine was often referred to contemptuously in colonial discourse.

No branch of modern science can be said to have developed almost exclusively under colonial ideological and political impetus than tropical medicine.

See Also

► Colonialism and Science

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Colonialism and Science

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From the very first decades, scientific advances played essential roles in European overseas expansion. Improved astronomical instruments and calculations and an array of new navigational devices and cartographic techniques made the Portuguese voyages into the uncharted South Atlantic possible. Subsequent voyages of exploration and (for the Europeans) discovery led to

further refinements of both instruments and navigational data and stimulated the introduction of ever more sophisticated ways of measuring time, distance, and location. Scientific curiosity was among the main motives of Europeans who planned or led expeditions of discovery and conquest. Astronomers and cartographers often sailed with explorers and merchants for the express purposes of testing new instruments, taking astronomical or meteorological readings from distant latitudes, and charting regions that had hitherto been unknown to the Europeans. The application of the data gathered on these voyages to improving maps, to compiling more accurate navigational charts, and to devising new instruments greatly enhanced European advantages over other peoples in navigation, trade, and warfare by sea.

As European armies and administrators advanced inland, first in the Americas and the outlying island of Africa and Asia and later throughout the globe, botanists and geologists followed, collecting "exotic" specimens to carry home to the gardens and cabinets of their rulers and national scientific societies. European savants examined and classified the bewildering mass of information and objects that flowed in from the rest of the globe, and struggled to fit it into the preexpansion world picture; or, more commonly, used it to build a new vision of both the earth and the cosmos. A host of self-appointed, usually amateur, ethnologists also reported extensively on the diverse peoples and cultures they encountered overseas. Their observations became the basis for elaborate, allegedly scientific, and invariably hierarchical classifications of human types. These classifications in turn provided evidence to support highly contentious theories regarding the relationships among human groups, usually termed races, and between humans and other species, particularly different varieties of apes.

Both in Europe itself and increasingly (but on a much reduced scale) in colonial enclaves overseas, scientific institutions – such as the Hortus Botanicus in Leiden, Kew in London, and the Sibpur botanical gardens in Calcutta – served as clearing houses for flora and fauna collected from around the globe and focal points for taxonomic inquiries and experimentation in procreation and hybridization. The elected members of Europe's scientific societies, most notably London's Royal Institution and the Académie des Sciences in Paris, provided the backing to mount scientific expeditions, certified that what were regarded as scientific procedures had been followed by the explorer or naturalist in question, and made the findings of overseas investigations available to the educated public of their respective nations and the European scientific community as a whole.

From the outset the scientific side of the process of European overseas expansion was all but monopolized by one of a number of approaches to the natural world that had jostled for supremacy in the medieval era and coexisted in the West since ancient times. The predominance of what recent scholars have characterized as the Baconian or mechanistic strain of scientific thinking in European colonial enterprises was of special importance. It meant that other options, such as the organic approach to nature and the cosmos, which might have been more compatible with and accommodating toward non-Western epistemologies, were excluded or relegated to marginal roles in this critical area of interaction between European and non-Western peoples and cultures.

The key attributes of the dominant Baconian or mechanistic strain of Western science rendered European colonial observers and policy-makers particularly unreceptive to non-Western ways of thinking about and interacting with the natural world. The underlying assumptions of the Baconian approach also strengthened the resolve of those among the colonizers who were ironically the most concerned with the well-being of the subjugated peoples to impose Western epistemological presuppositions and standards and procedures of investigation on colonized peoples. Though there were important differences among those scientists who adhered to the Baconian mode, it is possible to distil a number of key attributes that most colonial theorists and administrators would have agreed characterized the proper, or Western, approach to scientific

thinking. Though developed in the West and shown by recent research to have been vitally affected by the social and cultural milieux in which it arose, the science carried overseas by European colonizers was seen to be value neutral, objective in its procedures, privileging abstraction and reason, empirically grounded, and somehow transcending time and space and thus universally valid. These attributes gave the practitioners and advocates of Western science confidence that the spread of this epistemology – and the institutions and procedures associated with it – to the rest of the peoples of the globe was both beneficial and inevitable.

This view is, of course, still held today by many scientists as well as development specialists, social theorists, and assorted intellectuals with an interest in the so-called Third World. Its champions among the colonizers viewed the diffusion of Western science as part of a larger campaign to rationalize the world and conversely to banish what they viewed as superstitious or subjective, intuitively oriented epistemologies. Although only the most reflective and outspoken colonial observers would have acknowledged it, Western science was also aggressively expansive and intolerant of rival non-Western epistemologies – just as it had been of alternatives in Europe itself. By the early nineteenth century, it was also inextricably linked to the great technological advances that drove the Industrial Revolution, and the market-oriented, fossil fuel intensive, interdependent global order that was associated with the resultant transformation of the West. Thus, the Western scientific approach proved to be quite compatible with prevailing Western hegemonic ideologies, such as the *mission civilisatrice*.

Despite attempts to develop general paradigms for the diffusion under the aegis of European colonial domination of Western science, its role in the process of colonization and its impact on non-Western peoples and cultures varied widely by time and place. Important differences can be seen, for example, in the scientific fields and types of investigations that were prominently associated with overseas colonization before and after the Industrial Revolution. In the early centuries of exploration European scientists overseas were mainly preoccupied with astronomy, zoology, and botany. As Western Europe's need for markets and raw materials grew with the spread of industrialization, fields like meteorology, geology, chemistry, and applied mathematics became increasingly integral to the colonial enterprise. As European colonizers came to administer much of Africa and Asia directly, more sophisticated techniques of surveying, codifying, and statistical gathering became essential for activities as diverse as revenue collection and the formulation of legal codes. Recent scholarship has also shown that the relationships between colony and metropolis in terms of scientific investigation and exchange also shifted dramatically after World War I. These transformations were accelerated in the interwar years and after World War II by the process of decolonization, and a concomitant shift from an emphasis on extraction to a fixation with the rhetoric of development, which became enshrined in modernization theory after 1945.

The process by which Western science was diffused and its impact on overseas societies also differed greatly depending on the timing and nature of European interaction with non-Western cultures, the colonizers' assumptions about the level of sophistication of indigenous epistemologies and material cultures, and the actual attainments of colonized peoples in science and technology. The process of Western scientific diffusion, for example, in settlement colonies such as Australia and Canada, that had relatively small and scattered autochthonous populations, followed a very different course than in densely populated areas, such as South Asia and China, where small communities of European administrators, missionaries, and merchants encountered highly developed scientific and technological traditions with ancient links to their own.

Even within the different types of colonial societies there were critical variations. Thus, for example, the New World colonies in both Latin and North America, which were the first areas of extensive European conquest and large-scale settlement, were the sites of significant scientific

investigations and developed their own scientific societies as early as the eighteenth century. By contrast, Australia and New Zealand were not settled until the following century and were not integrated into the scientific networks of their European metropolis, Great Britain, until the late 1800s. In addition, from as early as the late seventeenth century, the pursuit of science was stunted in much of Latin America, as compared to Canada and the United States, due to Spain's long political and economic decline and its increasing marginalization as a center of scientific learning.

None the less, in all of the settlement colonies, indigenous learning, and epistemologies were pushed to the periphery. Ethnologists studied "aboriginal" beliefs and traditions for their folkloric or antiquarian value, not because they had anything to teach the colonizers about the ecology or topography of the lands they occupied, much less because they might stimulate major modifications in European understandings of the natural world. The research agendas of all of the settlement colonies were also largely dictated by the savants of scientific societies and institutions of higher learning in Europe itself. Though the size and the close links of the elite in the United States to Europe made original work by colonial scientists, such as Benjamin Franklin, more likely than in other settlement areas, until the early twentieth century settler colonists were primarily engaged in applied field research, heavily focused on the collection of local flora and fauna samples. Much of this work was directly linked to efforts to uncover and extract the great natural wealth of settlement areas. The empirical findings of New World botanists, geologists, or ethnologists, who were often merely temporarily transplanted Europeans, were mainly funneled to scientists in European centers for interpretation and theoretical elaboration.

After about 1900, scientific connections between European centers and settlement areas – both those still formally colonized and those, such as the United States, long independent – were radically transformed. Dominions, such as Canada and Australia, were accepted as partners, rather than assistants, in international scientific inquiry. The settlement areas more generally emerged as important centers of scientific research and theoretical innovation in their own right – as evidenced, for example, in Frederick Banting's discovery of insulin in Canada and Macfarlane Burnet's work on immunology in Australia. This was particularly true of the United States, where the already substantial growth of an internationally recognized scientific community early in the twentieth century was greatly accelerated in the 1930s by the forced migration of leading scientists from Europe, such as Albert Einstein. By the 1940s, this former colony and settlement area had taken the lead in many areas of scientific endeavor, from the most abstract theory to applied research.

In comparison with the tropical dependencies, where small numbers of Europeans ruled large and ancient African or Asian societies, the diffusion of Western science to the settlement areas met with little serious resistance. To begin with, the transfer was overwhelmingly to settler populations of European origins and heritage. This meant, on the one hand, that questions of racial ability with regard to the development of scientific communities and institutions in colonized areas did not arise, even though the arrogance of metropolitan savants was often a source of considerable discomfort for the colonials. On the other hand, because the dominant settlers despised and marginalized or discarded altogether the epistemologies of the indigenous peoples, there were no alternative thought systems or ways of doing to rival or provide foci of resistance to hegemonic Western scientific approaches.

Scientific friction between metropolis and settlement colony arose from personal and institutional rivalries, but scientists in both locales shared epistemologies, methodologies, and presuppositions about the place of humans in the natural order. Local resistance came not from subjugated indigenous peoples defending their own, very different traditions, but from the poorly (or un)educated majority of the settler population. The latter were not so much opposed as indifferent to the endeavors of a rather isolated

scientific elite, whose labors appeared to be wasted unless they could be turned to some immediate practical advantage. Thus, the key challenge for the scientific communities in the settler colonies was expanding popular understanding of and approval for scientific research, and winning government funding for scientific institutions and projects. Evidence of practical application was key to success in these endeavors, and thus a premium was placed on applied research, at least until the middle of the twentieth century.

The linkages between science and colonization in nonsettler areas of Africa, Asia, and Oceania, where small numbers of Europeans dominated large and diverse colonized populations, were markedly different than in Australia or the United States. Here it is important to distinguish between areas that the Europeans conquered outright and ruled directly, such as India and much of sub-Saharan Africa and Southeast Asia, and those they dominated indirectly or "informally" through military threats and periodic interventions, economic influence, and the manipulation of indigenous leaders. The latter areas would include most of the Islamic Middle East, Persia/Iran, China, Siam/Thailand, and Japan – until it became a Western-style scientific and technological power in its own right in the early twentieth century. Even within these two general categories of nonsettlers, critical distinctions need to be taken into account. Colonial policies regarding the diffusion of scientific learning and investigation, for example, were quite different in British India or French Indochina than in most of sub-Saharan Africa or the islands of the Pacific, even though all of these areas were formally colonized. Within the indirectly controlled areas in the informal spheres of influence, the European approach to Islamic societies in scientific matters differed in important respects from their interaction with China, Japan, or Thailand.

In some ways the diffusion of Western science in some formally colonized areas like India shared more with informally controlled areas, particularly China and the Islamic Middle East, than with Africa or the Pacific, which were ruled directly. In India, China, and the Middle East, the European colonizers recognized not only that the indigenous peoples had produced ancient and sophisticated civilizations – which usually meant that they had certain key attributes, including writing, specialized elites and cities – but that they had long nurtured scientific traditions of their own. Informed European observers even acknowledged that the West owed a large debt to Islamic peoples both for the recovery of much of classical Greek learning that had been "lost" to European civilization after the fall of Rome, and for original scientific advances made by Muslim peoples and transmitted to Europe through Arab and Jewish scholars in Spain and Italy. A handful of European observers also recognized that Islamic civilization had served as a vital conduit of scientific learning and inventions from civilizations further east, particularly India and China.

Recognition of the earlier scientific achievements of selected non-Western peoples informed the attitudes of European colonizers towards the diffusion of science in the societies so designated in important ways. In the early centuries of European overseas expansion, it fed mutual curiosity and ongoing interchange. The first Jesuit missionaries in China, for example, evinced a strong interest in Chinese astronomy, chemistry, and medical techniques. In India, Portuguese and later Dutch merchants and officials routinely consulted Indian physicians well into the eighteenth century. European physicians not only studied the prescriptions and techniques of Indian *vaidas* and *hakims*; they readily conceded the superiority of indigenous specialists in treating tropical diseases.

By the early decades of the eighteenth century, most European observers had concluded that even the most advanced, non-Western scientific traditions were hopelessly outdated and encrusted with superstition and quackery. If it survived at all, recognition of non-Western achievements was focused on the distant past. In the accounts of European authors who concerned themselves with matters scientific or technological, the stagnation of Indian or Chinese learning, in stark contrast to the ever-changing and highly progressive advance of Western knowledge, was

a constant refrain. In areas that escaped direct colonization, particularly China and Japan, scientific knowledge and technological expertise had been and remained the most effective ways for gaining access to Asian rulers and impressing Asian elites with the efficacy of Western ways, which seemed otherwise dubious, if not crude. None the less, the sense that peoples like the Chinese and Japanese had long been civilized and had once excelled in science and technology deeply affected the educational policies pursued by Christian missionaries, when they were permitted to proselytize in these areas, and the trading policies and diplomatic exchanges of the great powers. Japan as a whole closed in on itself after 1600, but Dutch traders at Deshima continued to make the latest European scientific treatises available to an emerging Japanese literati. Christian educators in China frequently pushed advanced training in the sciences (particularly medical) and mathematics. By the late-nineteenth century, regionally based segments of the Chinese scholar-gentry were avidly importing Western technologies in "self-strengthening" campaigns designed to ward off the imperialists' partition of the Middle Kingdom.

From the mid-nineteenth century similar patterns of diffusion can be found in other non-Western areas, which the Europeans regarded as long civilized but where they increasingly exercised informal sway. French missionaries strove to impress their Lebanese students with the superiority of Western scientific learning, while Siamese rulers strove to educate an elite corps in the engineering skills of the West. Because their own scientific traditions shared much with those of the Europeans – not the least a common, extensive borrowing from the ancient Greeks – the approach of the Muslim peoples of the eastern Mediterranean to these interchanges was somewhat different from that of the Siamese or, most critically, the Chinese. Having given so much to the West in the sciences, Arab and Turkic reformers could claim that it was in no way demeaning for Muslim peoples to borrow back in order to catch up to their European rivals. Though not all accepted this argument, it made the introduction of Western scientific learning palatable for those who supported advocates of forced "modernization," such as Muḥammad ʿAlī in Egypt and the Ottoman ruler Mahmūd II. Unable to make a convincing argument for such historical precedents, the Confucian literati of China vehemently resisted the introduction of Western learning or reluctantly conceded its necessity in the name of China's survival.

Although similar tensions were present in formally colonized areas that had longstanding scientific traditions, such as India, decisions about how much and what sort of Western scientific and technological diffusion should occur were taken out of the hands of the indigenous peoples. Colonization resulted in a growing influx of European scientists, engineers, and medical practitioners, and a great expansion in their activities and influence. The collection of flora and fauna that antedated colonial rule continued and in some respects expanded, but trained scientists and technicians were now employed by colonial administrations for massive and systematic geological and land tenure surveying operations. Statisticians oversaw census counts; botanists tested new plant varieties in state supported gardens; and hydrologists directed the overhaul and expansion of irrigation systems. As these activities suggest and scholars from formerly colonized areas have recently argued, science was a central pillar of the European colonial order.

Colonial science was also field-oriented, overwhelmingly applied, and devoted primarily to enhancing efforts to maximize the extractive potential of conquered areas. Its diffusion to the colonized peoples was consciously channeled and often constricted out of security concerns or fears of future economic competition. Rather than an abstract, objective and dispassionate concomitant of colonial expansion, Western science was the linchpin of rationalizing offensives that sought to reshape the thinking of colonized peoples, reconfigure the spatial relationships in colonized areas, and remake institutional frameworks and social relations in ways that accorded with Western epistemologies and presuppositions about the logical order of things.

Much of the literature on the diffusion of Western science in the colonial empires has concentrated on the biographies and activities of European scientists and on the policies pursued by European colonial administrators. As a consequence the varied and critical roles played by the colonized peoples in the dissemination of Western scientific learning and techniques have been obscured. At a range of levels, their contributions were essential. In the era when naturalists were dominant, the collection and identification of specimens would have been difficult, if not impossible, without Javanese or Indian guides and assistants, and villagers who were vital repositories of local knowledge about animal life or the rain forest. Working in the celebrated miniaturist tradition that peaked under the Mughals, Indian artists sketched flora and fauna in the field and often illustrated the published collections on these subjects that remain standard references to the present day.

As the grip of colonial administrations tightened from the middle of the nineteenth century, subjugated peoples found new ways to become involved in the scientific enterprises that buttressed the new order. Indian surveyors, engineers, and medical practitioners served in colonial administrations both in South Asia and British colonies in Africa and Southeast Asia. Indian chemists, physicists, and biologists worked for British firms, traveled to Europe for advanced study or to take up research positions, and increasingly taught in one of a growing number of universities in India itself. Indian doctors and surveyors set up private practice in colonial towns.

The assumption of many of these roles depended on the spread of higher educational opportunities open to Indians in the sciences and mathematics. The very existence and steady expansion of these opportunities underscores a vital difference between India and most of the other colonized areas. Here again, the colonizers' recognition of precolonial scientific attainments proved critical. The work of Sir William Jones and other "Orientalists" in the late-eighteenth and early nineteenth centuries left little doubt that ancient Indian civilizations had excelled in many of the sciences and mathematics. Though increasingly disdainful of these achievements and impressed with contemporary Indian backwardness in matters scientific and technological, key colonial officials who strove to reform Indian society premised their educational initiatives on the assumption that Indians could master the most advanced Western scientific learning and mathematical techniques. This assumption and the policy decisions regarding higher education that followed gave Western-educated Indians much greater agency in the process of the diffusion of Western science than was enjoyed by any other colonized people. By the last decades of the nineteenth century, racist objections to these policies were raised by both prominent officials and private individuals. However, the path breaking work done by such Indians scientists as Ray and Bose made a shambles of the racists' aspersions, and bolstered the demands of Indian nationalists for greater opportunities in higher education, particularly in the Western sciences.

With the partial exception of colonies like French Indochina and the Netherlands Indies, opportunities for advanced training in the Western sciences in much of the rest of Asia, sub-Saharan Africa, and the Pacific islands were minimal or nonexistent. In these areas, scientific work was the monopoly of the European colonizers. As in settlement areas, such as Australia and the United States, indigenous epistemologies and local knowledge were dismissed as irrational, ignorant, and superstition-bound. These might be studied in order to understand the "native mind" to control the colonial populace better. However, they had nothing to contribute to Western scientific learning or methodology. Thus, in most nonsettler colonies, which the Europeans deemed devoid of scientific traditions of their own, racist assumptions regarding the mental capacity of the indigenous peoples insured that little or no advanced training in science or mathematics was available. These policies in turn left most colonized peoples ill-prepared for a postcolonial world where Western scientific knowledge and skills have proved vital for successful economic competition, development planning, and many aspects of intellectual discourse.

The colonizers' disdain for indigenous epistemologies and approaches to the natural world has also obscured a number of other important patterns involving the interaction of science and colonialism. However extensive or limited the volume of Western science diffused to different colonies, in all there was a persistence of indigenous scientific thinking and practices. In some cases the colonizers themselves were complicit in this process, as when the British made use of Indian *hakims* and *vaidas* in their campaigns to eradicate epidemic diseases, such as smallpox and cholera in India, or when merchants or officials in Africa resorted to local cures for snakebite or dysentery. In some colonies, most notably India but also in Kenya, Senegal, Indonesia, and other areas, the defense of indigenous epistemologies and procedures was explicitly linked to the nationalist assault on the European colonizers. In the thinking of visionary leaders, such as Mohandas Gandhi, the restoration and reworking of these traditions posed what well may be viable alternatives to the approaches to economic and social development championed by the industrial West.

In virtually all of the formerly colonized societies, non-Western approaches to science in areas as diverse as medical practice, preservation of soil fertility, and care for the emotionally disturbed have persisted. In view of the clear limits in terms of resource exhaustion, environmental degradation, and social inequity of both major Western development alternatives – market-capitalist and socialist command economy – this persistence may ultimately prove critical. It may be that the predominant direction of scientific diffusion will be reversed; that approaches to work, resource use, social organization, and economic well-being pioneered by Gandhi and other non-Western thinkers will have much to offer the beleaguered societies of the postindustrial world.

See Also

► Ethnobotany
► Knowledge Systems: Local Knowledge

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Colonialism and Science in Africa

Gloria T. Emeagwali

By 1914, most of the African continent had been subordinated to colonial rule, with 36 % of African territory seized by the French, 30 % by the British, and the remaining 34 % dominated by Belgium, Germany, Italy and Portugal. This of course was not done without bloodshed. Millions of Africans died in the process of resistance against the invasion of the continent, waging guerrilla warfare for as many as 30 years in some cases. Colonialism was essentially a process of administration which denied Africans political and economic autonomy while subordinating them to the dictates of an evolving global capitalist ethic and world market controlled by a Euro-American elite. Indigenous science and technology were adversely affected by it. Ironically though, institutions such as the British Imperial Institute, through its Scientific and Technical Department, actually aided in the transfer of existing scientific and technical know-how from the colonies to the metropole.

One of the major effects of colonialism was the subordination of science and science education to the logic of colonial production and class structures. Science and technology development in most cases ceased to emanate from the womb of African civilization and indigenous problem-solving and experimentation. A new set of norms, values and relations of production was introduced and superimposed on existing precapitalist structures. In so far as colonialism was an exploitative system geared toward the redeployment of resources in the form of mineral and agricultural wealth, from the periphery to the center, it necessarily led to the destabilization of existing processes of accumulation of knowledge and technique. Colonial capitalism was geared primarily toward the export of surplus from the continent, and colonial education was to focus primarily on the creation of a new collaborative, nonthreatening elite supportive of the colonial agenda and committed to the running of the colonial (and neo-colonial) machine. It was less geared to innovation and creativity than to servile complicity.

References to glass-making and iron fabrication may illustrate the extent to which indigenous capability was undermined. As a consequence of the relatively cheap glass products from Europe dumped on the Nigerian market, indigenous glass producers ceased to produce glass from local raw materials such as silica and potash and proceeded to simply re-smelt and refashion imported European glass objects. In the case of iron there was a deliberate attempt to undermine indigenous initiative by the introduction of the "scrap iron policy" whereby metal designed as "scrap" was imported into the region from Britain. It has been argued that this policy was a deliberate attempt on the part of the British to replace iron products with those from European factories. The policy succeeded in strangulating the local metallurgical industry and arrested the further development of indigenous technology in this field.

The Scientific and Technical Department of the British Imperial Institute, located in London, was aimed at the acquisition of knowledge with respect to various indigenous technologies through experimental research, technical trials, and commercial valuation from within the vast colonial domain, including African colonies. The Institute consisted of a series of well-equipped research laboratories, and a supporting staff of trained scientists and researchers kept active in the analysis of natural and manufactured products from the colonies. Specific attention was placed on medicinal plants and it was explicitly stated that the numerous plants held in high repute as medicinal agents in the colonies should be investigated both as regards their active ingredients and their medicinal value. The above guidelines led to experimentation on *Khaya senegalensis* and a variety of Guinea corn, amongst others, plants held in high repute by indigenous experts. Traditional medicinal knowledge, integrated into the British scientific laboratory, was in fact a contributing factor in pharmaceutical development in the metropolitan center in the first three decades of the twentieth century. Research activity was not confined to medicinal plants, however, and one of the areas of investigative research was textile, specifically silk. Loni or Boko silk from Bauchi, Nigeria was one of those products analyzed. An up-to-date display of the various research findings was kept in the Galleries of the British Imperial Institute, London, and was of particular interest to merchants and industrialists on the look out for new products. Details were provided on application to the Commercial Information Office of the Institute or other authorized officers.

It is clear therefore that colonialism had far reaching implications for both the colony and the metropole. It weakened indigenous African capability with respect to experimentation, problem-solving and the creation of indigenous utilitarian objects and processes. At the same time though it facilitated the transfer of knowledge from Africa and other colonial dependencies while leaving in return an education system more geared to the reproduction of Christian religious norms and values and alienation than the further development of scientific and technological capability.

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Colonialism and Science in India

Deepak Kumar

Colonization was not merely a political phenomenon; it had far-reaching economic and cultural ramifications. It was an exercise in power, control, and domination. Scientific and technological changes greatly facilitated this progress. Technoscience and colonialism are closely linked and to some extent share a cause and effect relationship. In recent years a good deal of work has been done on the nature, course, and consequence of this relationship in different geographical and culture areas. Some scholars see in it utilitarian and developmental images; many others find it utterly exploitative, while some prefer to opt for a middle path and emphasize both the regenerative and retrogressive aspects of the science and colonization nexus. So the debate continues, and several works have appeared with case studies on Africa, Latin America, and Asia. India, being a prime example of classic colonization, has also received considerable attention.

The fact that India has a very long techno-scientific tradition and a rich cultural heritage is fairly well known. It was, however, during the seventeenth to eighteenth centuries, the post-Renaissance epoch (that of Descartes and Newton) that Europe began to outdistance India in scientific and material advancement. The rise of modern science in Europe profoundly disturbed the balance of scientific development among traditional societies. It is also possible that the various sciences and technologies were on a decline in India around 1790. There was definitely no "conscious" spirit of technological innovation and scientific enquiry to match the spirit of Europe. The result was colonization.

The advancing European trading companies became deeply involved in political and military rivalries, culminating in the establishment of the British paramountcy over the Indian sub-continent. A new empire was in the making. The colonizers were out to collect the maximum possible information about India, its people and resources. They reported what was best in India's technological traditions, what was best in India's natural resources, and what could be most advantageous for their employers. The English East India Company, for its part, was quick to realize that the whole physical basis of its governance was dependent upon the geographical, geological, and botanical knowledge of the areas being conquered. The colonizers fully recognized the role and importance of science in empire building.

The most interesting feature of this early phase of colonial science lies in its highly individualistic character. State followed the trade, and certain individuals on the spot would largely determine what was advantageous for both. These colonial scientists would try their hands at several fields simultaneously, and were in fact botanist, geologist, zoologist, physicist, chemist, geographer, and educator – all rolled into one. As data gatherers they had no peers, but for analysis and recognition, they had to depend upon the metropolitan scientific culture whose offshoots they were and from which they drew sustenance. The colonial government quickly patronized geographical, geological, and botanical surveys; after all these were of direct and substantial economic and military advantage. Medical or zoological research did not hold such promises. Research in physics and chemistry was simply out of the question, for there were no laboratories, equipment, or specialized training. The reigning spirit remained that of exploration. Systematization or analysis of its results had to wait for some time, but then, even disjointed and often haphazard studies served some purpose.

Other positive achievements were the establishment of scientific bodies and museums. Pre-British India never had anything like as scientific society, not to say a journal, which could provide some sort of a platform for scientific workers. William Jones was the first to realize this and founded the Asiatic Society in Calcutta in 1784. This society soon became the focal point of all scientific activities in India. It was followed by the Madras Literary and Scientific Society (1805), the Agricultural and Horticultural Society of India (1817), Calcutta Medical and Physical Society (1823), and the Bombay Branch of the Royal Asiatic Society (1829). Trigonometrical and topographical surveys were organized under the Great Trigonometrical Survey of India (1818), and a Geological Survey was established in 1851. Scientific research thus for a long time remained an exclusive governmental exercise, and this largely determined the nature and scope of scientific research in India. Colonial science primarily implied "natural history" and its star (if not sole) attraction was the exploitation of natural resources. It was basically plantation research with emphasis on experimental farms, the introduction of new varieties, and the various problems of cash crops. Next came surveys in geology and meteorology. Another major area of concern was health. The survival of the army, the planters, and other colonizers was at stake. The importance of medical research was always recognized, but the quantum of emphasis varied from time to time. In any case, however, research was not to be a curiosity-oriented affair. Financial considerations were invariably there. The colonial administrators consistently held that

scientists in India should leave pure science to Britain and apply themselves only to the applications of science. They would goad the various organizations to work along only economically beneficial lines. Colonial researchers often found themselves unable to distinguish between basic and applied research. This was particularly true of the geologists and the botanists. Their problem was how to discover "the profitable mean course" in which scientific research, having a general bearing, would at the same time solve the local problems of immediate economic value. The dilemma was fairly acute.

In the field of education, science was unfortunately never given a high priority. In 1835 Thomas Macaulay not only succeeded in making a foreign language, English, the medium of instruction, but his personal distaste for science led to a curriculum which was purely literary. A few medical and engineering colleges were opened, but they were meant largely to supply assistant surgeons, hospital assistants, overseers, etc. What India got was some sort of a hybrid emerging out of a careless fusion between literary and technical education. What is more, adoption of English as the sole medium of instruction in science rather hampered its percolation to the lower classes. Colonial education widened the social gulf and accentuated the age-old divide. Even in government institutions, growth was kept under a self-regulatory check. The Tokyo Engineering College was established in 1873, much later than the Engineering College at Roorkee, and by 1903 it had a staff of 24 professors, 24 assistant professors, and 22 lecturers. The Massachusetts Institute of Technology was established in 1865 and by 1908 it had 306 teachers. And Roorkee, even after 100 years of its existence (i.e., in 1947), had only 3 professors, 6 assistant professors, and 12 lecturers.

Colonialism involved not only exploration and classification but also coding and decoding cultures. Its cultural projects showed deeper penetration and greater resilience than its economic forays. With the help of schools, universities, textbooks, museums, exhibitions, newspapers, etc. local discourse was influenced and colonized. Modernity was presented as a colonial import and not something intrinsic to humanity's rational nature. Colonial rule, with its sharp tools, dissected and bared differences and was not inclined to synthesize. Colonialism usually stalls the possibilities of exchange and prefers one-way traffic. One may talk of transfer – transfer of knowledge, systems, or technologies – but it was a transfer restricted or guided to achieve certain determined objectives. As education and awareness grew, several Indians participated in the official scientific associations and institutions, but very often they searched for a distinct identity and established institutions, scholarships, and facilities of their own.

In the first half of the nineteenth century, Bal Gangadhar Shastri and Hari Keshavji Pathare in Bombay, Master Ramchandra in Delhi, Shamhaji Bapu and Onkar Bhatt Joshi in Central Provinces, and Aukhoy Kumar Dutt in Calcutta worked for the popularization of modern science in Indian languages. In 1864 Syed Ahmed founded the Aligarh scientific Society and called for the introduction of technology to industrial and agricultural production. Four years later Syed Imdad Ali founded the Bihar Scientific Society. These societies did not live long. In 1876 Mahendra Lal Sarkar established the Indian Association for Cultivation of Science. This was completely under Indian management and without any government aid or patronage. Sarkar's scheme was very ambitious. It aimed not only at original investigations but at science popularization as well. It gradually developed into an important center for research in optics, acoustics, scattering of light, magnetism, etc. In Bombay, Jamshedji Tata drew up a similar scheme for higher scientific education and research. This was opposed by the then Governer-General, Lord Curzon. Yet it finally led to the establishment of the Indian Institute of Science at Bangalore in 1909. There was thus greater awareness by the turn of the century.

In the first quarter of the twentieth century, those who put India on the scientific map of the world were J. C. Bose, who studied the molecular phenomenon produced by electricity on living

and nonliving substances, ► Ramanujan, a mathematical genius, and P. C. Ray who analyzed a number of rare Indian minerals to discover in them some of the missing elements in Mendeleef's Periodic Table. C. V. Raman's research on the scattering of light later won him the Nobel Prize in 1930 and gave the name to Raman spectroscopy. Meghnad Saha pioneered the field of astrophysics, while S. N. Bose's collaboration with Einstein led to what is known as the Bose-Einstein equation. These were great sparks, individual and sometimes lonely, yet imbued with both scientific and national spirit. They thought over what role science and technology would play in building modern India, and they dreamt of freedom. The colonial government was aware of its limitations and discomfiture, and gradually permitted greater indigenization of its scientific institutions and cadre. In the wake of the First World War the government realized that India must become more self-reliant scientifically and industrially. It appointed an industrial commission in 1916 to examine steps that might be taken to lessen India's scientific and industrial dependence on Britain. However, few of the Commission's recommendations were actually implemented. Discontent continued to grow. India's national leaders appreciated the importance of science and technology in national reconstruction and worked closely with the scientific talent of the time. A National Planning Committee was formed in 1937 for this purpose, in which several leading Indian scientists and technologists participated. In 1942, the Council for Scientific and Industrial Research was established. The end of colonial science was pretty near. With the A. V. Hill Report in 1944 on Scientific Research in India, the curtain dropped.

The foregoing analysis illustrates that in a colonial situation field sciences may have been developed through imported scientists as an economic necessity, but little fundamental research was possible. A few colonial scientists made important contributions that no doubt enriched science in general, but their activities hardly succeeded in introducing science to the Indian people or in ameliorating their condition. Colonial science did, on the whole, support and help sustain exploitation and underdevelopment.

See Also

► Ramanujan
► Western Dominance

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Colonialism and Science in the Americas

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When the Europeans arrived with Christopher Columbus, they found the set of explanations and dealings with natural realities that constituted the scientific knowledge of the peoples of the newly found lands absolutely novel. They marveled at the constructions, urban organization, clothing, and ornamentation of these peoples, mistakenly called Indians. To explain and understand what they were witnessing, European knowledge was not appropriate. The surprise was total.

Viking traders, and probably some other European, Asian, and African navigators, had previously visited these lands. There is evidence of this in or about the tenth century, but the records of these visits did not reach what we call the official literature.

The Portuguese were the most advanced people in Europe in navigational knowledge. People interested in navigation would study at the court of King Dom Joào II, in Lisbon, and frequent the entourage of the Infante Henrique, his son in charge of the navigation projects. Astronomers, ship builders, and pilots from all over the world were there. Among them was Martin Behaim, who, upon returning home to Nürnberg in 1490, was asked by his city authorities to produce a report on his studies abroad. He presented this in the form of a model of the Earth: a globe which he called the *Erdapfel*. There, between Europe, Asia, and Africa, shown in a detailed picture, lay a vast mass of water.

Surely views like this convinced Christopher Columbus, also a student in the court of Dom Joào II, of the possibility of reaching Cipangu and the domains of Grand Kahn. He convinced the King and Queen of Spain, Fernando and Isabel, who financed a fleet of three ships, which left Palos, near Seville, on 3 August 1492.

On 12 October 1492, they landed on an island called Guanahani in the language of its inhabitants. They did not recognize where they had landed; Columbus and the others believed they had reached Asia. The early days of the conquest and first encounters with the natives are related in descriptions of the conquest, by Columbus himself and by other chroniclers.

What the Spaniards encountered, as far as science and technology are concerned, is described in the entry on "► Colonialism and Science in the Americas" in this encyclopedia. The centuries preceding the arrival of Columbus saw a political process very similar to the one which took place in Europe in the Middle Ages, when principalities and other smaller domains were uniting into larger organizations such as kingdoms and nations. The Spanish conquerors were able to destroy the emergent power elites and replace them with the power of the conqueror, based on a well-balanced state-church structure controlling the means of production.

In Central America there was a tax system based on collecting products, while in the Inca Empire, tax was paid in labor. We can identify something that approaches private property and commerce in the Aztec model, while among the Incas the State is all powerful in the economy. Recent research reveals important commercial development in the coastal area of Peru and the beginnings of economic uses of sea resources. Although by and large the economic practices are similar to those in Europe, there is no indication at all of something that resembles capitalism. Maybe these are examples of noncapitalist economies. It is important to note the relatively low use of technology in agriculture. For example, they had no plowing devices and practically no fertilizers. Thus, production relied more on human factors, such as a more attractive division of lands with well-coordinated forms of cooperation and control of distribution, than on the intensive use of technology. At the same time, a considerable intervention of the state in major infrastructures such as irrigation and roads, associated with a rather efficient tributary system, indicates economic models which differ from those in the Old World (Europe and Asia). This is an important area of scholarship.

This was the situation the conquerors encountered when they met the highland civilizations. Before that two of colonial settlements had been created in the Dominican Republic: Isabela in 1494 and Santo Domingo in 1496. In the beginnings of this process, with agriculture depending on Indian slave labor, local tribes were exhausted. This caused slave-hunting expeditions to the other islands of the Caribbean. To the South, the arrival of the Portuguese Pedro Alvares Cabral in Brazil led to an exploratory mission by Amerigo Vespucci, in 1501, under the Portuguese crown. The establishment of colonial settlements waited until 1532, when Martim Afonso de Sousa founded Sào Vicente in coastal Brazil. In 1534 the Portuguese king divided Brazil into large areas, the *capitanias*, mostly coinciding with the current coastal states of Brazil and with the right of property to be inherited. This family distribution of the lands of Brazil established much of the style of land possession in the Portuguese colony.

Meanwhile, the search for slaves led the Spaniards to found Puerto Rico in 1508, Jamaica in 1509, and Havana in 1511. From there to Florida was a small step for Juan Ponce de León in 1513. The exploration of the coast of the Gulf of Mexico by Alonso de Pineda was completed in 1519. Also, Vasco Nuñez de Balboa led the remnants of the failed expeditions of Alonso de Ojeda and Diego de Nicuesa to Colombia and Panama to the Pacific Ocean and the founding of Panama in 1519. From there the exploration of the Central America and Mexico and incursions to South America were obvious steps. Founding several cities, the conquerors approached the heart of the Aztec and Inca empires.

The recognition of high civilizations in the region approached by the Spaniards led to political, religious, and philosophical disputes. Under instructions by the King of Spain to establish trading relations, Hernán Cortés contacted the Aztec King Moctezuma. Attracted by the richness of the Aztecs, Cortés joined with peoples conquered by the Aztecs against Moctezuma and ingeniously used Aztec mythology as a war

strategy to defeat him. Cortés completed the conquest of the region and established the Kingdom of New Spain. In 1539, he was recalled to Spain, leaving behind an empire stretching from the northern part of South America to the southern part of the United States, up to the Colorado River.

The successes in Central America led to efforts to conquer South America. In 1530 Francisco Pizarro reached Peru and won over the Inca Atahualpa, who was killed after being baptized. Resistance to the conquerors lasted until 1572, with a prolonged siege of Cuzco, the old Inca capital, ending with the capture and beheading of the last Inca, Topa Amaru. From Peru, the conquest was carried on to the south and north. Founding of the cities of Quito (1534), Lima (1535), Buenos Aires (1536), Asunción (1537), Santa Fé de Bogotá (1538), Santiago de Chile (1541), Potosí (1545), La Paz (1549), and Caracas (1562) completed the period called "the Conquest." All of Latin America, with the exception of the Amazon Basin, was in the hands of the Spanish and the Portuguese. Attempts by the French and the Dutch to conquer regions in Brazil did not succeed.

In the colonial times that followed, we see the exploitation of the lands and resources and of the peoples of the conquered regions. The colonizers brought with them traditional European agricultural and mining techniques with which they exploited the native production, mainly in metallurgy. The colonizers changed the means of production. This was done to a great extent indirectly. The native religions were simply destroyed. Food habits were also considerably modified. Wheat, rice, coffee, citrus, sugar cane, and bananas were all grown for export. This had severe consequences for the nutrition of the natives. Famine, never known in pre-Columbian times, became a major concern for Latin America. Urbanization, again following the styles of Europe, led to the development of architectural styles unsuitable to the weather and geological conditions of the conquered lands. This can be traced to the current inadequacy of the cities in the face of natural disasters such as earthquakes, floods, and high winds.

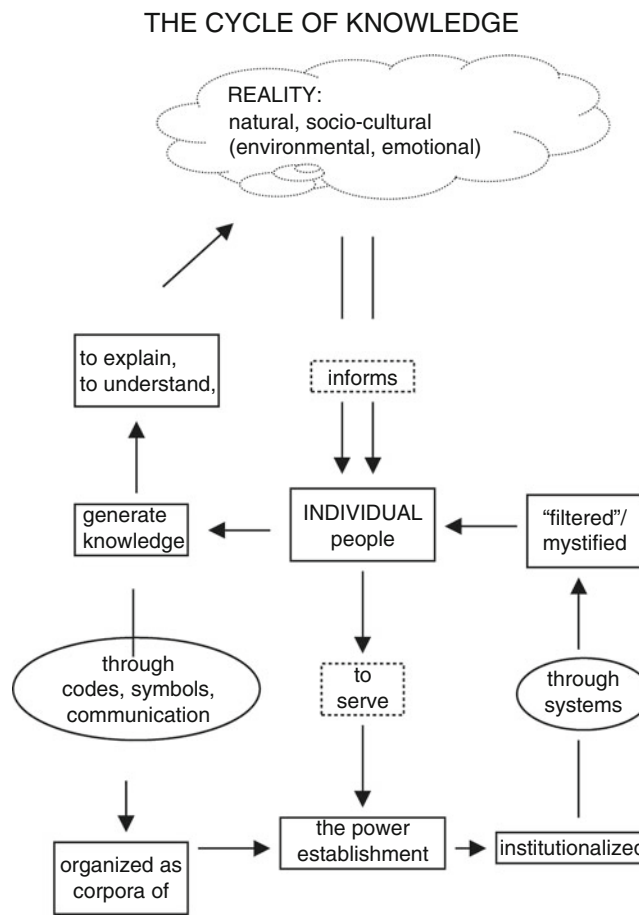
In the sciences in general, Latin America was the recipient and not the producer of scientific advances. The peripheral status of the countries was maintained throughout independence. Indeed, the colonial style and submission of the native population, with land distribution determined by the conquerors and colonizers, were kept after independence. Independence was for the *criollos*, never for the native populations, throughout the three Americas. Even after independence, education was modeled on the former imperial system.

Colonial science, considered as contributing to the mainstream of scientific development, is at best very modest. It is very important to recognize isolated cases, but they do not add to universal scientific development. Native contributions are almost exclusively in medicine, particularly in pharmacology.

The development of Native American science and philosophy was interrupted with the conquest and colonization. Remnants of pre-Columbian forms of knowledge are limited, and research today only begins to reveal their depths.

An explanatory note: this entry is a critical appraisal of science, technology, and society in the Americas. It deals primarily with the social support for science, technology, and mathematics in colonial Latin America. Other forms of knowledge come naturally in the exposition. They are mutually interdependent and cannot be separated. The frequent references to mathematics reflect the perception that modern science relies, after the success of Newton's *Principia*, on mathematics. Hence, there is sometimes a confusion between science and mathematics, as well as between science and technology. Most of the times we refer only to science, but the reflections imply technology and mathematics. This is the characteristic of the research program, which underlies this entry, called ethnoscience or ethnomathematics.

Every culture generates knowledge as a response to mystical, environmental, and economic demands. The major challenge is to understand the human condition, which aims for survival and transcendence. Survival of the individual and of the species depends on the encounter with nature as a whole, which includes others



Colonialism and Science in the Americas,
Fig. 1 The cycle of knowledge

of the same species capable of cooperation for procreation. The encounter is in the moment, is present. Transcendence results from backing survival by searching the past, trying to understand birth and creation, probing into the future, and questioning death and posthumous influences, and this determines behavior.

Individual knowledge, as well as behavior, is the response to these drives, which implies gregariousness. Individuals are organized in groups, in the broad sense, as families, tribes, communities, and societies in general, and develop communication strategies. These strategies allow for exchanging individual knowledge and generating group knowledge and agreeing on compatible behavior. The culture of a group may be defined as shared knowledge and compatible behavior of the group.

How is knowledge shared and how is behavior made compatible? In other words, how are they generated, intellectually and socially organized, and diffused? These questions are closely related and schematized in Fig. 1.

Science, as well as language, religion, arts, astronomy, mathematics, and techniques, is a corpus of knowledge that have been generated, organized, and diffused in a particular context, with specific motivations. Eventually, the corpora of knowledge become unsatisfactory and subject to criticism and revision. This may be the result of internal cultural factors or, what is very common throughout the history of mankind, as a result of exposure to other cultures. Both the internal and external factors are present in cultural dynamics.

Science in History

The great navigations since the sixteenth century mutually exposed forms of scientific knowledge from different cultural environments. The several ethnosciences involved in the encounters, which obviously include European science, have been subjected to great changes as a result. Ethnoscience, as a research program, focuses on corpora of knowledge established as systems of explanations and ways of doing, which have been accumulated, through generations, in specific cultural environments. This program, typically interdisciplinary, brings together and interrelates results from the cognitive sciences, epistemology, history, sociology, and education. An essential component is the recognition that science and mathematics are intellectual constructs of mankind, in response to the needs of survival and transcendence.

The need for an intellectual framework to organize the corresponding systems of explanations and codes and norms and practices gave rise to many aspects of science and mathematics (D'Ambrosio, 1994). In this research program, particular attention is given to those dimensions of knowledge which bear some relation to what became known as science and mathematics in the European civilization after the fifteenth century.

Today, many of the weather explanations and predictions, agricultural practices, culinary, production systems and commerce, dressing, and institutional codes, such as the legal system, processes of cure, languages, religion, and philosophy, which, as a complex, constitute science, come from the European tradition developed in the Middle Ages and the Renaissance. They were imposed, after the sixteenth century, to much of the world, in the processes of conquest and colonialism. But we see, all over the world, extant practices performed in various levels of intensity and in very distinctive ways. These practices, which have their origins in native communities, have been, and continue to be, significantly modified as a result of mutual exposition of cultural forms. For example, it is common to see indigenous peoples in the Americas using Indo-Arabic numerals, but performing the operations from bottom to top, explaining that this is the way trees grow. In the more advanced nations, it is not difficult to identify the influence of this mutual exposition in priorities and even styles of scientific action.

Priorities and styles of intellectual action are the substrata upon which new knowledge is built. Thus, new knowledge reflects the individual and cultural history of the agent and reveals the diversity of extant cultures. This is the essence of a multicultural historiography, which is the framework in which we discuss the history of science in Latin America. A new educational posture depends on a new historical attitude which recognizes the contribution of past cultures in building up the modern world and modern thought and which avoids omissions and errors of the past treatment of cultural differences.

We easily identify two categories of scientific knowledge: (1) academic science, sometimes called formal or scholarly science – generated by a restricted professional community; organized as specialties or disciplines, according to a convenient epistemology; and shared with peers through an elaborated language – and diffused through strictly controlled institutions, academic, or governmental, and (2) traditional science, also called cultural science, popular science, practical science, and street science, resulting from everyday practices and common knowledge.

These names are challenged. Many scholars do not agree with using the word "science" with a qualification, reserving the word only for the former and using simply "traditions" for the latter. The main distinction refers to criteria of rigor and truth and to the nature, domain, and breadth of its pursuits. Science is subjected to a concept of truth supported by criteria of rigor and organized in disciplines. The criteria of rigor, hence the concept of scientific truth, are changeable in the light of new evidence. In other words, permanence is not strict in science, which led to scientific evolution or revolutions. This is the main issue behind the Popper-Kuhn controversy. In the traditions the focus of concern and the methods are, necessarily, holistic. Traditions reveal, sometimes explicitly, mystical features, characteristic of revealed truth, giving a sense of

permanence to their fundamental principles. Thus, scientific knowledge tends to be skeptical, while traditional knowledge is more prone to fundamentalism.

Indeed, sciences and traditions are closely related and influence each other. Skepticism and fundamentalism are the consequences of the resistance to recognize the mutual influence. The ethnoscience program is the recognition of this mutual influence. Its main objective is to understand, through a concept of cultural dynamics, this influence.

For example, pre-Columbian cultures had different styles of doing their measurements and computations, and these practices are still prevalent in some native communities (Closs, 1986). Most Amazonian tribes have counting systems that go, "one, two, three, four, and many." And that is all, since with these numbers they can satisfy all their needs (Salvador, 1965, pp. 89–90). We also see important ways of dealing with pottery, tapestry, and everyday knowledge with strong mathematics characteristics in several cultures. The people from these cultures have no problems at all in assimilating the current European number system and deal perfectly well with counting, measurement, and money when trading with individuals of the European culture demands it. Land measurement, as practiced by peasants in Latin America, comes from ancient geometry transmitted to medieval surveyors since land property and measurement (geometry) is strange to pre-Columbian cultures.

The high prestige of science comes mainly from its recognition as the basic intellectual instrument of progress. Modern technology depends on science, and the instruments of validation in social, economic, and political affairs, mainly through storing and handling data, are based on science and mathematics. Particularly important in this respect is statistics, which brings to science an aura of essentiality in modern society. There is a general feeling that there are practically no limits to what can be explained by science. Many of the applications which give science such a prestigious position are part of various forms of cultural conflict (D'Ambrosio, 2000).

Some Remarks on Historiography

History, as a major academic discipline, carries with it an intrinsic bias which makes it difficult to explain the ever-present process of cultural dynamics which permeates the evolution of mankind. This paves the way for paternalism and arrogance and for intolerance and intransigence. This interferes with the understanding, by a cultural group, of the processes of building up cultural realities which respond to the need for survival and transcendence of another cultural group.

This is seen in the encounter of the two worlds, Europe and America, in the processes of conquest and colonialism. The origin of the interference may be related to distinct views of nature. A scientific conceptualization, which resulted from the medieval intertwining of Judaic, Christian, and Greco-Arabic thoughts in Europe, led man to look at nature and at the universe as an inexhaustible source of richness and to exploit these resources with a mandatory drive toward power and possession, ignoring native cultural, economical, spiritual, and social diversities. Man was created, in the biblical tradition, to obey the Creator and to be the master of all the creatures.

In the history of science, these biases have been methodological, as well as ideological. The fact that to pursue historical analyses one talks about the sciences, such as physics, chemistry, or mathematics, as distinct from religion, art, or politics, is an obstacle to understanding the processes of evolution of ideas and methods, of reflection and action, which underlie man's struggle to find explanations and to understand and cope with his environment, as well as to find means of conviviality with nature.

One of the main difficulties in doing the history of science in Latin America concerns the chronological division. In what follows, geographical divisions and historical periods are defined according to the general chronology associated with the conquest and colonization of the Americas.

Geographic divisions are defined following the administrative organization in viceroyalties: (1) New Spain (roughly what is today Mexico,

Guatemala, and upper Central America), (2) New Granada (roughly what is today southern Central America, Costa Rica, Panama, Colombia, Venezuela, Ecuador), (3) Peru (roughly what is today Peru and Bolivia), (4) La Plata (roughly what is today Chile, Paraguay, Argentina, and Uruguay), and the lately created Viceroyalty of (5) Brazil, under the Portuguese crown. Since the independence movements, which began early in the nineteenth century, the cultural map has remained roughly the same.

With respect to periods, it is misleading to adopt, for the New World, the same division as in the history of science in Europe. I propose five major periods:

1. Pre-Columbian era
2. Conquest and early colonial times
3. Established colonies
4. The rise of independent countries
5. The twentieth century (which will not be dealt with in this entry)

These periods reflect the established societies before the conquest, the emerging classes of Creoles, the definition of production and political systems, and international geopolitics, which have, mainly in the twentieth century, major influences in the sciences and technology in Latin America. Of course, there are specificities. While recognizing important attempts of French and Dutch settlements in the Americas, the main colonial role was played by Spain, Portugal, and England. It is important to understand the different styles of these three colonial empires.

Portugal, since its early consolidation as a kingdom, in the thirteenth century, recognized the Atlantic as its essential link to its commercial interests. The limited means of production led Portugal to develop a potent scientific and technological establishment focused on the navigations. The European navigators of the end of the fifteenth and early sixteenth centuries reached all of America, Africa, India, and China. In the case of Africa and in Asia, there had been previous contacts with civilizations which had many encounters among themselves and with the Europeans. Thus, the encounters of the fifteenth and early sixteenth centuries were amplifications and deepenings. Meeting the "new," the unknown, and the unexpected was experienced by Columbus and the Spaniards, in 1492 and in the subsequent voyages to the New World.

Visions of the World

Earlier contacts with the Americas are known, but the motivations and behavior of earlier navigators were completely different from the Spanish and Portuguese and afterward the English, French, and Dutch. (See the interesting study of Ivan Van Sertima: *They Came Before Columbus*, New York: Random House, 1976 and the reports on the voyages of the Chinese monk Huei Shen in the fifth century to Mexico. See the communication of Juan Hung Hui: "Tecnologia Naval China y Viaje al Nuevo Mundo del Monje Chino Huei Shen", III Congreso Latinoamericano y III Congreso Mexicano de Historia de la Ciencia y la Tecnologia, Ciudad de Mexico, 12–16 Enero 1992.)

The influence of the navigators and chroniclers, particularly Portuguese, in building up the mode of thought which underlies modern European science is noticeable. In the words of Joaquim Barradas de Carvalho, "the authors of the Portuguese literature of the navigation made possible the Galileos and the Descartes" (de Carvalho, 1983, p. 13), essentially through the development of "objective and serene curiosity, rigorous observations and creative experimentation" (Correia, 1940, p. 468).

Particularly important as chronicles are the *Crónica dos feitos de Guiné* of Gomes Eanes de Zurara (1453) and the *Esmeraldo de situ orbis*, by Duarte Pacheco Pereira, written between 1505 and 1508. These, particularly the latter, are probably the earliest major scientific works reporting on what was observed and experimented in the newly "discovered" environments.

The voyages themselves allowed a broader view of the world. For the Portuguese, to venture into the Southern Hemisphere demanded two major enterprises: the construction of the caravel, an extremely versatile ship built by the

Portuguese in the fifteenth century as the result of a remarkable engineering project, and novel navigation techniques, relying on tables constructed from systematic recorded observation carried on by the commanders of those ships. (See Antonio Cardoso, As Caravelas dos Descobrimentos e os mais Ilustres Caravelistas Portugueses, Monografia n° 7 do Museu de Marinha, Lisboa, 1984.) As the first European looking at "different skies," they were responsible for recording what they saw. The contributions of Gil Eanes crossing the Bojador Cape in 1434 and Nuno Tristão reaching in 1443 the coast of Mauritania and the major achievement of Diogo Cão crossing the equator line in 1483 all paved the way for Bartolomeu Dias to cross the Cape of Good Hope in 1488 and for Vasco da Gama to reach Calicut in India, in 1498. Together with Columbus reaching the Western lands in 1492, the vision of the world changed. All lands and peoples were within the reach of the navigators. It was the beginning of a new phase in the history of mankind.

Conquest and Early Colonial Times

America, and to some extent Africa, was more surprising to the Europeans than the lands which had been reached before by land routes, in the so-called Old Continent. Particularly, America showed peoples with new systems of explanation, of rituals, and of societal arrangement. Reflections on natural philosophy or the physical sciences, particularly astronomy, were part of the overall "Cosmo" vision of the pre-Columbian civilizations.

The scientific establishment and native scientists, surely present in the society of the conquered cultures, were not recognized as such by the conquerors. One of the earliest registers of these cultures, Fray Bernardino de Sahagún (1499–1590) writes that "The reader will rightfully be bored in reading this Book Seven, [which treats astrology and natural philosophy which the naturals of this New Spain have reached] … trying only to know and to write what they understood in the matter of astrology and natural philosophy, what is very little and very low" (de Sahagún, 1989, p. 478). This important report explains much of the flora and fauna as well as the medicinal properties of herbs of Nueva España. But he does not give any credit to indigenous formal structured knowledge. This is typical of what might be called an epistemological obstacle of the encounter.

In the vision of the conquered, a great impression was caused by the arms, tools, and equipment in general, as seen in pictures, for example, in the *Codice Florentino*. Much research is needed on the science of the encounter. But this needs a new historiography, since names and facts, on which current history of science heavily relies, were not a concern in the registry of these cultures. A history "from below," which might throw some light on the modes of explanation and of understanding reality in cultures, has not been common in the history of science.

Mexico, in itself, has a very rich colonial history. Developments in Central and South America reveal the important and strategic position of Mexico in the New World.

To acquire fluency in the language of the conquered peoples was a priority. Grammars are a major contribution to this. As early as 1547, Fray Andrés de Olmos (ca. 1485–1571) published the *Arte de la Lengua Mexicana*. Fray Domingo de S. Thomas (ca. 1505–1570) published in 1560 the *Grammatica o Arte de la Lengua General de los Indios de los Reynos de Peru*. The need for this understanding of the culture of the conquered, where much of the mining was taking place, is also seen in numeracy. A description of the number system of the Aztecs was written by Juan Diaz Freyle: *Sumario compendioso de las quentas de plata y oro que en los reinos del Pirú son necessarias a los mercaderes y todo genero de tratantes. Con algunas reglas tocantes al arithmética*. Printed in Mexico in 1556, this is the first arithmetic book printed in the New World. This is a clear indicator that the successful elimination of basic communicative instruments supporting the means of production and the religion of the conquered, such as language and numeracy, had to be mastered by the conqueror. Soon after the consolidation of the conquest, this

book disappeared from circulation, and Aztec arithmetic was replaced by the Spanish system; the Spanish language also became dominant.

Printing of scientific books in Mexico reveals the intellectual atmosphere of Nueva España. Alfonso (Gutierrez) de la Veracruz published, in 1954, *Recognitio Summularum* and *Dialectica Resolutio* and, in 1557, *Phisica Speculatio*. The first book contains an exposition on Aristotle's theory of syllogisms, including modal logic, and the second contains Aristotle's "Categories," with commentary, and includes numerous examples drawn from geometry, such as parallel lines, triangles, and the incommensurability of the diagonal of the square. (I owe this information to Bruce S. Burdick.)

It is interesting to observe that the registration of space location did not have the same importance as language and numeracy. Maps, essential in European actions, were not known in these cultures, while time measurement was done with remarkable precision. This has much to do with the differences in what I call Cosmo vision. (An important study of these differences is that of Fernando Flores Mirador: *Tierra firme antecipada. El descubrimiento de América y las raíces arcaicas de Occidente* (to appear), Lund, 2003.)

Although different production systems and societal organization prevailed in the Atlantic Coast, under Portuguese rule, efforts to master the language were also important. In 1595, José de Anchieta S. J. (1534–1597) published the *Arte de Grammatica da Lingoa Mais Usada na Costa do Brasil*, and in 1640, when Spanish interests grew in the Eastern South America, mainly focused on the Jesuitic Missions in Paraguay, Antonio Ruiz de Montoya S. J. (1585–1652) published the *Arte y Bocabvlario de la Lengva Gvarani*.

In early colonial times, the Spanish and the Portuguese tried to establish schools, mostly run by Catholic religious orders. The effort to impose the language of the conqueror was responsible for considerable advances in linguistics. The demand for science and mathematics was essentially for economic purposes related to trade, but there was also an interest in science and mathematics related to astronomical observations. Reliance on indigenous knowledge was limited, but there was some interest in the nature of native knowledge. The *Historia Natural y Moral de las Indias*, published in Seville in 1590 by Joseph de Acosta S. J. (1540–1600), is representative of the trend to write comprehensive studies of society, history, religion, and science.

Already in the first century after the conquest, there were practical books published in Mexico, such as the *Arte menor de arithmetica*, by Pedro de Paz, in 1623, and *Arte menor de arithmética y modo de formar campos*, by Atanasio Reaton, in 1649. It is also to be noticed the book *Nuevas proposiciones geométricas*, written by Juan de Porres Osorio, in Mexico.

There are some sources for the history of the natural and the health sciences in the general books of the chroniclers. In the conquest, there was a high level of scientific curiosity to observe and understand new diseases and new cures. Indeed, Felipe II (1527–1598), of Spain, sent his personal physician, Francisco Hernandez (ca. 1514–1597), to Mexico, to learn and record new practices and drugs which might be useful in improving health care in the cities. Unfortunately, all of his manuscripts were destroyed in a fire at the Escorial Library.

It is important to remember that social medicine was more developed in Portugal and Spain, as well as in England, than in the rest of Europe. Upon the arrival of ships to and from the New World, it was necessary to provide medical care for the travelers, in many cases subjected to new and unknown diseases. The *Santas Casas* (holy houses), founded in Lisbon in 1498, were built with this purpose. In 1543, Bras Cubas founded a *Santa Casa* in Santos, near São Vicente, one of the earliest urban settlements in the Portuguese colonies, founded by Martim Afonso de Sousa. Soon there was concern about creating formal medical classes in the colonies. In 1653, a Chair of Medicine was established in Nueva Granada, in the Colegio Mayor de Nuestra Señora del Rosario, in Bogota. This lasted until 1865 and was replaced by the Facultad de Medicina de la Universidad Nacional, in 1867. (A detailed history of this chair of medicine is the book by

Emilio Quevedo and Camilo Duque, *História de Cátedra de Medicina*, *1653–1865*, Centro Editorial de la Universidad del Rosario, Bogota, 2003.)

Astronomy was a major area of interest in Latin America in the seventeenth century. There are important discussions on the meaning of comets. Many of the interpretations related to the purpose of such strange phenomena: to convey divine messages to mankind. Surely, these were searches for scientific explanations. Several polemical exchanges of letters and papers are known from these times, with important epistemological arguments. The figure of Don Carlos de Sigüenza y Góngora (1645–1700), of Mexico, towers. His works focus on astronomical observations and calculations. His most important book, considered one of the most important works of Latin American science, is *Libra astronómica y filosófica*, written in 1690. In it, Sigüenza y Góngora refutes prevailing astrological arguments about comets.

In Brazil, research on comets was also of major importance. We can see the same tone of the reflections of Sigüenza y Góngora in the work of Valentin Stancel S. J. (1621–1705), a Jesuit mathematician from Prague who lived in Brazil from 1663 until his death. His astronomical measurements are mentioned in Newton's *Principia*. A polemic, which includes another Jesuit, Antonio Vieira S. J. (1608–1697), reveals how important was the discussion about the nature of comets in building up modern scientific ideas.

In the Viceroyalty of Peru, we have the same concerns. The first to be recognized as a mathematician in Peru was Francisco Ruiz Lozano (1607–1677), who wrote *Tratado de los Cometas*, essentially a treatise of medieval mathematics explaining the phenomenon.

The Established Colonies

The death of Carlos II (1661–1700), of Spain, resulted in a turbulent period in Europe, known as the War of the Succession of Spain (1701–1714). An important consequence was the intellectual movement known as the Enlightenment (*Ilustración*), which had important consequences for the Americas, mainly the intellectual revival, which began in Spain under Carlos III (1716–1788) and in Portugal under José I (1714–1777) and his strong minister, the Marquis of Pombal (1699–1782) (Maxwell, 1995).

Religious orders were not immune to the new ideas coming from Europe, and several descriptive treatises of the world were written. A general geography of the continent, the *Geographia Histórica de la América y de las Islas Adyacentes*, *y de las Tierras Arcticas y Antárcticas*, *y Islas de los Mares del Norte y del Sur*, authored by Pedro Murillo Velarde S. J. (1693–1753), was published in Madrid, in 1752, as volume IX of a monumental 10-volume *Geographia Histórica del Mundo*. This important and comprehensive presentation of the New World is a remarkable source of the history of the development of the colonies, revealing the political struggles and cultural differences.

As a result of the War of the Succession of Spain, relations with other European nations were intensified, and, as a consequence, a number of foreign scientific expeditions, with mixed scientific and commercial interests, came to the region during the eighteenth century (Weinberg, 2000, pp. 497–515). This contributed to shaping scientific development in Latin America. Great repercussions were caused by the scientific expeditions of Amedée Frézier (1682–1773), published in 1716 as *Relación del viaje por el mar del Sur a las costas del Chile y del Perú realizada durante los años 1712*, *1713 y 1714*, and of Charles Marie de la Condamine (1701–1774), whose main results were published as *Relation abrégé d'un voyage fait dans l'inté rieur de l'Amerique méridionale*. Alejandro Malaspina (1754–1809) organized one of the most important expeditions. In 5 years, they visited practically all the Spanish possessions and collected precious materials.

A good number of expatriates and Creoles played an important role in creating a scientific atmosphere in the colonies. As a result of the emergence of modern science, following the publication of Newton's *Principia*, mathematics was central in the emerging scientific community. A number of intellectuals, well versed in a variety

of areas of knowledge, were responsible for introducing mathematics to the colonies. These include Juan Alsina and Pedro Cerviño in Buenos Aires, who lectured on infinitesimal calculus, mechanics, and trigonometry. In Peru, Cosme Bueno (1711–1798), Gabriel Moreno (1735–1809), and Joaquín Gregorio Paredes (1778–1839) are best known. In Brazil, José Fernandes Pinto Alpoim (1695–1765) wrote two books, *Exame de Artilheiros* (1744) and *Exame de Bombeiros* (1748); both focused on what we might call military mathematics, and both were written in the form of questions and answers. (Brazil was different from the Spanish colonies; she did not have presses. These two books, although written in Brazil, focusing on Brazilian interests, were printed, in Portuguese, in Spain and Portugal.)

A distinguished figure from the period is José Celestino Mutis (1732–1808), who was responsible for an unpublished translation of Newton but also for the introduction of modern mathematics in Colombia, mainly relying on the books by Christian Wolff. He was the founder of the *Observatorio de Bogotá* in 1803. His most distinguished disciple, Francisco José Caldas (1771–1816), became the director of the Observatory. Caldas was deeply involved in the Independence War and was shot by the Spaniards.

In Chile, the Universidad Real de San Felipe, which was inaugurated in 1747 in Santiago, was provided with a "catedra" of mathematics. Fray Ignacio León de Garavito, a self-instructed Creole mathematician, was responsible for this chair.

Again we have to mention Mexico, where the most important developments of mathematics in Latin America at that time took place. In the first half of the eighteenth century, a number of textbooks on geometry, arithmetic, and astronomy were in use in Mexico, written by local scholars. These were mostly minor scientific works. In the second part of the century, there were publications with more scientific value. Particularly notable are the *Lecciones matemáticas* of José Ignacio Bartolache, published in 1769. In 1772, an unknown person built a "calculating wheel," capable of performing the four basic operations for numbers up to 10^8 digits. Also in 1772, Benito Bails published the *Elementos de matemáticas*, which treated infinitesimal calculus and analytic geometry.

A special kind of applied mathematics was developed, stimulated by the complexity of problems related to water and to mining. These two constitute the most important problems in the technological development of the country. "Subterraneous geometry" became a major theme in Mexican science. The needs of mining led to the creation of mining schools, such as the Real Seminário de Minería, founded in Mexico City by the Spanish mineralogist Fausto de Elhuyar in 1792. Particularly important were the efforts for urbanization, which took place in all the colonies (Catalá, 1994). The book *Comentarios a las Ordenanzas de Minas*, by Francisco Javier Gamboa, published in 1761, is most representative of these developments.

Let us move to the South. In Guatemala, which included Costa Rica, the most renowned scholar was José Antonio Liendo y Goicoechea (1735–1814). He taught at the Universidad de San Carlos de Guatemala. This had already become a very important academic center after a new plan of studies published in 1785, written in Latin in the form of 25 theses, under the title *Temas de Filosofia Racional y de Filosofia Mecánica de los sentidos, de acuerdo con los usos de la Física*; *y de otros tópicos físico-teológicos según el pensamiento de los modernos para ser defendidos en esta Real y Pontificia Academia Guatemalteca de San Carlos*. This was, essentially, a medieval proposition. Goicoechea was responsible for modernizing this plan of studies, incorporating experimental physics into the project, and introducing modern mathematics based on the texts of Christian Wolff.

Independence: The Basin Metaphor

The independence of the Viceroyalties of Nueva España, Nueva Granada, Peru, La Plata, and Brazil was achieved in the first quarter of the nineteenth century. The political division in countries, following independence, was

practically the same as today. The pattern of cultural dynamics since colonial times did not change much, except for the fact that other empires replaced Spain and Portugal as central nations.

There is no way to deny that (Western) science and mathematics are essential in the modern world. Public opinion is ready to support investment in scientific and mathematical research in spite of being absolutely unable to guess what kind of research is being supported. For example, peers and society in general regard those that get good grades in mathematics as potential geniuses, while those that do not do well in mathematics are regarded as potentially stupid. Socially, this has been instrumental in the selection of the elite. The attitude regarding sciences in general is not different. The appropriation, by larger strata of society, of scientific and mathematical terminology, and even results, is reprehended and even derided. Those who do well in the arts or in sports, but fail in mathematics, are considered less intelligent. The references to "hard sciences" subtly reveal contempt for the humanities and social sciences. The best illustration of this is what became known as the "Science Wars," exposed by Alan Sokal's hoax. (See the issue devoted to the theme "Science Wars" in *Social Text*, 46–47, Spring/Summer 1996. The issue has very interesting papers. Regrettably, attention was given only to the hoax of Alan Sokal. As a consequence there was a renewal of attacks on Afrocentrism, warnings against a "new dark age of irrationalism," and other controversial disputes going on in the academic world. All this, which might be interpreted as a form of intellectual fundamentalism, is nothing but a defensive posture against the challenge of the current epistemological order.)

Let me introduce some concepts and reflections that result from what is now called Social Studies of Science or Science Policy. This is basically the study of the politics of scientific development, the backbone of funding agencies. It is very interesting to analyze the substitution of the colonial discourse by the discourse of aid – both multilateral, like UNESCO, and bilateral, like ORSTOM, the British Council, and others. The nature of the deprived populations in colonial times and after independence, following WWII, did not change. Neither did basic needs. But the strategies to keep them as faithful consumers had to change. (These topics have in the postwar period drawn much attention and generated important studies whose results throw some light on the production of scientific knowledge throughout history. Particularly interesting is the historiography adopted by Harold Dorn in his exciting book, *The Geography of Science*, Baltimore: The Johns Hopkins University Press, 1991.) But let us not deviate from the main objective of this entry, which is the production of scientific and mathematical knowledge.

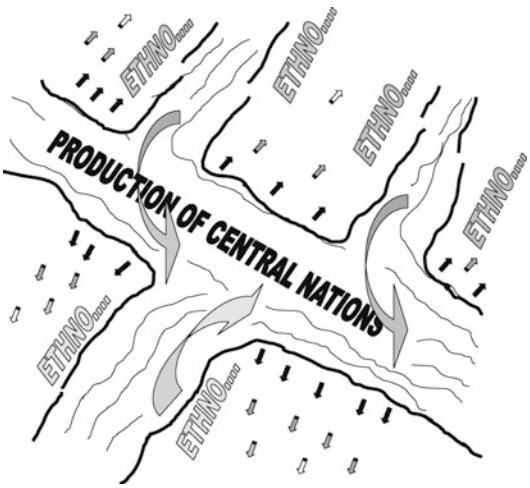
When deciding on investments in science and technology, it is natural to expect social benefits. These investments have been substantial, both through funding agencies, either governmental or through aiding agencies, either bi- or multilateral. The outcomes in the so-called Third World have not been encouraging, as recently mentioned by the Director-General of UNESCO. "The gap between rich and poor countries is a gap of knowledge," said Federico Mayor (1994). Over 80 % of the benefits of scientific and technological research are available only to the populations of the First World. But the gap between central nations and peripheral nations in the production of scientific knowledge is widening. Scientific productivity is related to the cultural atmosphere and self-esteem. Evidence from research shows that both individual and social creativities are enhanced by self-esteem. Self-esteem can hardly prevail among a population deprived of its history.

The most efficient strategy to consolidate colonial control was to deprive the conquered peoples of their systems of explanation and the instruments for survival and transcendence. This was achieved with a subtle deprivation of the history of the conquered and the production of a history "favorable" to the conqueror. This prevailed after independence. Today, Cardinal Richelieu and D'Artagnan are themes of history and literature in former colonies. Hernán Cortez is better known than Moctezuma. Local heroes are ignored or labeled as evil criminals.

For example, in Brazilian history books, Zumbi (1655–1695) was regarded as an outlaw, and although recognized, more recently, as a hero, the space reserved to him in books and classes is negligible. (Zumbi is the leader of the "Quilombo dos Palmares," a republic created by runaway slaves in the northeast of Brazil, which lasted for about 100 years. It was destroyed in the late seventeenth century. But other such republics lasted and some were contacted only recently. Their economy and production systems, particularly agriculture and mining, are as yet to be studied. See more on the communities of runaway slaves in the Americas in Richard Price's, org., *Maroon Societies*: *Rebel Slave Communities in the Americas*, 2 vols. Baltimore: The Johns Hopkins University Press, 1972.)

We may consider, as it is frequent in discussions of policy, especially in the United Nations and other national and international agencies, the production of scientific, technological, and mathematical knowledge as something measurable. Scientometrics relies on several indicators, and the studies of quantitative history allow us to speak of the central nations as those who produce new knowledge and the peripheral nations as those who absorb new knowledge. Production and absorption of knowledge are clearly distinguishable. The sad situation is that the peripheral nations have been slow in absorbing new knowledge. The lack of infrastructure acts as a barrier for this process (D'Ambrosio, 1975, p. 94). The basin metaphor helps us to understand the process. The main producers of knowledge (central nations) are represented by the mainstream. Water always fertilizes their margins. They will produce their effect in the margins of the tributaries (peripheral nations) much later, when the waters have already flown along the stream (thus producing the gap or obsolescence of knowledge). The water (knowledge) does not flow upstream of the tributaries (Fig. 2).

The water of the tributaries fertilizes their margins and also adds and contributes to the volume of water of the mainstream. For example, expropriation of "popular" knowledge – so common in the pharmaceutical industry – and co-optation strategies, particularly the brain drain, encourage this. A strict school system was responsible for this strategy in colonial times. This is manifest in the emigration of academics and, worst, in the subordination of laboratories and research institutions of the peripheral nations to the priorities of their major homologues in the central nations (D'Ambrosio, 1979, pp. 223–229). This strategy plays out, for example, in the valuation of foreign academic degrees over local degrees. Now, it is quite revealing to see the efforts to entice research institutions in the peripheral nations to join major biotechnology research plans.



Colonialism and Science in the Americas, Fig. 2 The basin metaphor

The co-optation of scientists in the periphery is normally done by sending experts, in many cases scientists with high reputations, to the periphery for short visits and conferences, by offering fellowships, by giving stipends higher than the current national salaries, by sending equipment (in many cases obsolete or already heavily used), and by offering international travel to seminars and congresses. This is true in academics and, in the more developed peripheral nations, also in industry. Particularly in mathematics, we have numerous examples of such practices in the postwar period. The presence of monies of the US Army, Navy, and Air Force research agencies, as well as of the NSF, the CNRS, the British Council, the DAAD, and

other agencies, following the pattern mentioned above, is remarkable.

These cases have not been studied in detail as yet. They have the common feature of producing human resources and results without any analysis of the capability of the peripheral countries to absorb and to make these resources and results useful for their needs. Normally this is the result of a lack of qualitative directives in science policy of the peripheral nations. Practically every scientific development plan in the periphery is a program entirely based on quantitative goals. The World Bank, the UNDP, and other financing agencies rely on, indeed stimulate, plans based on quantitative goals. Clearly, they are easier to check. But the benefits for the poor populations of the peripheral nations are practically nil.

In the basin metaphor, the sources of the rivers, both the mainstream and the tributaries, correspond to ethnomathematical knowledge. Ethnomathematical knowledge, like the waters, flows fertilizing the margins of the tributary and eventually mixes in a major stream, contributing to this flow. Waters of the mainstream do not go upstream through the tributaries.

The notion of progress carried on by the mainstream will benefit the margins of the tributary after a long way through difficult land paths – which correspond to the acquisition of knowledge from other sociocultural and environmental sources. The needs of the margins – peripheral cultures – are met by the water of the tributaries and only later receive the benefits coming from the mainstream. But these can be useful only if the grounds are fertile. To make them fertile requires long, deep, and very complex educational reforms.

In this metaphor, an alternative to mainstream and tributaries would be to have a large lake, where all the sources contribute equally to the main body of water. Each source produces according to its environmental history, and all the waters of the lake fertilize all the margins. The creation of the great lake – the deterioration of the current world order – is identified with a sensible globalization, leading to a new planetary order.

Developments in the Newly Independent Countries

The independence of Guatemala, in 1821, decreased the influence of Mexico in Central and South America. The establishment of new universities and the renewal of old ones, immediately preceding and after independence, generated open attitudes with respect to sources of knowledge on which to build up the newly established countries of Latin America. Formerly restricted to an almost exclusivity of influences coming from Spain and Portugal, the new countries attracted considerable attention from the rest of Europe, and a new wave of scientific expeditions came to South America. They had great influence in creating new intellectual climates throughout the region. This new source is seen very strongly in the building of large and diversified libraries, both public and private, and the acquisition of modern literature.

In Costa Rica, colonial authorities established the Casa de Enseñanza de Santo Tomas in 1814, in which the most influential teacher was Rafael Francisco Osejo, born in 1780. In 1830, he wrote *Lecciones de aritmética*, written in the form of questions and answers, a common feature in that period, as shown above when referring to Alpoim in Brazil. In 1843 the Casa de Enseñanza de Santo Tomas was transformed into the Universidad de Santo Tomas, where courses in engineering were established. But there were no courses in pure sciences and mathematics.

Colombia soon attracted foreign mathematicians. The Frenchman Bergeron introduced descriptive geometry in the country, and the Italian Agustín Codazzi (1793–1859) was influential in creating the Colegio Militar. Lino Pombo (1797–1862), who was particularly influential in founding the Academia de Matematicas de Venezuela, wrote a complete course of mathematics.

In Brazil, the transfer of the royal family of Portugal, who were escaping the Napoleonic invasion, in 1808, was decisive in changing cultural life in the colony. The Portuguese court settled in Rio de Janeiro, where it was necessary to create an infrastructure to run, from a colonial town, the vast Kingdom of Portugal. They

founded a major library and an Escola Militar (Military School), the first institution of higher learning in the colony. Both were influential in the development of mathematics in Brazil. In the school, a doctorate in mathematics was established and a number of theses were submitted and defended (da Silva, 1992). Translation of the textbooks of Lacroix, of Legendre, and of others was quite important in generating what we might call a mathematical style in Brazil.

Particularly interesting is the case of Joaquim Gomes de Souza (1829–1863), known as "Souzinha," the first Brazilian mathematician to appear in Europe. He presented his results in the Académie des Sciences de Paris and in the Royal Society. Only short notices of the papers were given, and they were posthumously published as *Mélanges du Calcul Intégral*, as an independent printing by Brockhaus of Leipzig in 1889 (*Comptes-Rendus de l'Académie des Sciences de Paris*, tomes XL, p. 1310, and XLI, p. 100, and *Proceedings of the Royal Society*, 1856, pp.146–149). (It is quite interesting to read the referee's reports and the reaction of Gomes de Souza to the fact that Liouville did not give an appraisal of the paper, according to Gomes de Souza, because of "la petite jalousie." A thorough study of the scientific works of Gomes de Souza has still not been done.) This work, dealing mainly with partial differential equations, is permeated by very interesting historical and philosophical remarks, revealing access to the most important literature then available. This was possible due to the existence of important private collections in Maranhão, his home state in the northeast.

Argentina, independent since 1816, experienced a remarkable intellectual development. In 1822, the ephemeral Sociedad de Ciencias Físicas y Matemáticas was founded in Buenos Aires (Nicolau, 1996). There was an emergence of private libraries. Particularly important is the private library of Bernardino Speluzzi (1835–1898), which listed the main works of Newton, D'Alembert, Euler, Laplace, Carnot, and several other modern classics. Another intellectual, Valentin Balbin (1851–1901), while rector of the National College of Buenos Aires, proposed a new study plan, in 1896, which included history of mathematics as a distinct discipline. This is probably the first formal interest in the history of mathematics in South America, which eventually led to an important school of history of science in Argentina.

In Peru, there was an interest in statistics, beginning with the book *Ensayo de estadística completa de los ramos económico-políticos de la provincia de Azángaro…* by José Domingos Choquechuanca (1789–1858), published in 1833.

In Chile, the Universidad de Chile was created in 1842, with a Faculty of Physical and Mathematical Sciences. A most distinguished member of the faculty was Ramón Picarte, a lawyer, who had his paper, *La división reducida a una adición*, accepted and published by the Academy of Sciences of Paris in 1859. (I did not have personal access to these papers and to the records of Picarte's presence in Paris.) Much emphasis was given to teacher training. An agreement with the government of Germany provided the pedagogical support to reform education in the country. Fifteen German mathematicians, most with a doctorate, immigrated to Chile in 1889.

The influence of Auguste Comte (1798–1857) toward the end of the century was very important in all of Latin America, particularly in Mexico and in Brazil. Although the main reason was the demand of the emerging political elites to build up the ideological framework of the new countries, Comtian ideas influenced a considerable development of mathematics and the Sciences in general. (See the important doctoral dissertation of Circe Mary Silva da Silva, Positivismus und Mathematikunterrichte: Portugiesche und franzsische Einflüsse in Brasilien im 19. Jahrundert, IDM, Bielefeld, 1991.)

Conquest and colonization had an enormous influence on the course of development of civilization. The chroniclers of the conquest tell of different ways of explaining the cosmos and the creation and of dealing with the surrounding environment. Religious systems, political structures, architecture and urban arrangements, sciences, and values were, in a few decades, suppressed and replaced by those of the conqueror. A few remnants of the original behavior

of these cultures were and still are outlawed or treated as folklore. But they surely integrate the cultural memory of the peoples descending from the conquered. Much of these behaviors are easily recognized in everyday life.

Mathematics, as a human endeavor, is not different. This is one focal point of the research program known as ethnomathematics, which deals with the generation, the intellectual and social organization, and the diffusion of different ways, styles, modes (*tics*) of explanation, understanding, learning, coping with, and probing beyond (*mathema*) the immediate natural and sociocultural environment (*ethno*). This clearly results from the mutual exposition of different cultures, and the dynamics of this process is a major problem we face in doing the history of ideas in every region of this world.

The conquest paved the way to colonization. In the Americas, the early colonizers, the Spanish and the Portuguese, paved the way for the French, the English, and the Dutch colonizer and later on for Africans, Europeans, and Asiatic immigrants. With them came new forms of coping with the environment and of dealing with daily life and new ways of explanations and learning. The result was the emergence of a synthesis of different forms of knowing and explaining which were generated by and available to the different communities, to workers, and to the people. We recognize the emergence of new religions, cuisine, music, arts, and languages, particularly in the Americas – the Creoles. All of these interrelated as a synthesis of the cultural forms of the ancestors.

Science and mathematics, as cultural forms, are not different. The emergence of new cultural behavior is another focal point of the research programs known as ethnosciences and ethnomathematics.

Particularly in the Americas, the variety and peculiarity of the expositions of cultures and the specificity of the population migrations reveal an effort of the colonizer to transfer, with minor adaptations, the forms of social, economical, and political organizations and administration prevailing in the metropoles, including schooling and scholarship (academies, universities, monasteries). The new institutions in the Americas were based on the styles prevailing in the metropoles, mostly under the influence, and even control, of religious orders.

All this, which took place during most of the sixteenth, seventeenth, and eighteenth centuries, occurred while new philosophical ideas, new sciences, new ways of production, and new political arrangements were flourishing in Europe. The cultural artifacts produced in Europe were assimilated in the Americas under specific, mostly precarious, conditions. There is a clear coexistence of cultural goods, particularly knowledge, produced in the Americas and abroad. The former were consumed mostly by the lower strata of society, the people and workers, and the latter by the domineering classes. These boundaries are not clearly defined, and the mutual influences of the resulting intellectual productions are evident.

This poses the following *basic question*: What are the relations between the producers and consumers of cultural goods?

This guides my proposal for the historiography of science and mathematics and what I have called "the basin metaphor." Although this is a question affecting the relations between academia and society in general, hence between the ruling elites and the population as a whole, it is particularly important for understanding the role of intellectuality in the colonial era. Thus, ethnoscience and ethnomathematics are fundamental instruments of historical analysis (D'Ambrosio, 1995, 1996).

Curiously enough, the main factor influencing the consumption of what we might call academic science and mathematics produced in an alien cultural environment, sometimes inside the same country, depends basically on what the "outsiders" – that is, the people not learned in science and mathematics – have to say about science and mathematics. This factor has not been given attention in the prevailing historiographies (D'Ambrosio, 1993). This broader look, suggested by new historical scholarship, comes under severe attack, in what became to be known as the Science Wars (D'Ambrosio, 2000). My proposal incorporates to the history of science

and mathematics, in an essential way, the views of aliens, in the sense of strangers to the specific knowledge fields or strange to the cultural environment, about science and mathematics.

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C

Colonialism and Science in the Malay World

Hairudin Bin Harun

By the sixteenth century, the legends of the Golden Chersonese, about the distant land having more gold and exotic treasures than people, were well established among the sea going nations of Europe. Legend had it that the Golden Chersonese was geographically located midway between India and China. The Golden Chersonese description apparently fit the Malay Peninsula very well. Indeed, it came to be known among the early Europeans by that very name until it was replaced by another, Malacca. By whatever name the Peninsula was known, it was a major focal point of Eastern trade. Indeed, Malacca – actually a tiny coastal city-port situated in the middle of the Malay Peninsula – was not only a commercial Mecca, but also a cultural center and meeting point for the major civilizations of the time.

In 1575, Louis De Roy, writing on the virtues of the new knowledge and inventions spurned by the Renaissance spirit, made a special note about the meeting of Magellan and the King of Malacca. According to De Roy, the meeting was

made possible by the new knowledge of the seas and the use of the magnetic compass for navigation. Malacca, to the Europeans then, as not just a reference to the city-port but rather to the whole Malay Archipelago, including the Peninsula and Islands of Indonesia that were under Malaccan rule. By the time De Roy's article was published. Malacca had actually been under the annexation of Portugal for 65 years, since the Portuguese defeated the Malays in 1511. Some scholars have suggested that the downfall of Malacca also marked the decline of Eastern scientific and technological superiority *vis-à-vis* the European. Others have cautioned against making simplistic conclusions, pointing out that the reasons for the downfall of Malacca were far more complex than those that have been suggested.

The Portuguese ruled Malacca until the mid-seventeenth century. In 1614 the Dutch successfully wrested Malacca from the Portuguese. By the mid-eighteenth century Dutch power in the Malay Archipelago declined, giving way to the British. The British were relatively latecomers to the region, but they were none the less regarded as the best prepared – intellectually, militarily and economically – among the colonizers of the region. They were poised for a long stay.

There were two major factors that were crucial to the expansion and consolidation of the Crown's influence: the colonial economy and the health of officials, colonialists, and *coolies* (colonial laborers). In the early phase of British colonialism, spices, timber, and other agricultural products were the backbone of the colonial economy. Knowledge of economically and medicinally useful plants of the East was indispensable both for the sustenance of the economy and the maintenance of health. This knowledge was to be found in the new discipline of plant science, later known as *economic* botany, and much later as *agricultural science*.

The cultivation of spice trees, and the transfer of economic plants like rubber trees from the Amazon to the Malay Peninsula, was some of the colonial activities made possible by the new plant science and its scientific institutions. Indeed, apart from medicine, no branch of science was regarded as so crucial to the sustenance of colonialism as economic botany. Before the advent of synthetic drugs, herbs and plants were the main source of medicines. For instance, quinine, an extract from the chichona tree that grew wildly in the Peruvian jungle, was extensively used to cure malarial fever. Hence, knowledge of the indigenous plants was important not only for economic reasons, but tot health as well. Health and diseases also assumed an economic and political significance. They were moderating factors in the colonial expansion and exploitation of the East, especially in the tropics. Tropical diseases like malaria were a menace to the health of colonial officials and then laborers. Indeed, malaria reportedly wiped out some of the remote British colonies and military bases and was blamed for slowing down colonial campaigns in the Far East and Africa. In the following discussion we will see how the development and history of British ► colonialism and science in the Malay Archipelago became intertwined.

Botany and British Colonialism

As early as the seventeenth century there were attempts to grow exotic and foreign food crops away from their natural habitats. The first attempt to grow pineapples in England was reportedly made during the reign of Charles II (1660–1685). The colonization of the New World and later, Asia, led to the introduction of many new crops to Britain. Maize, a staple crop of the Native Americans, which yields ten times more than wheat, was among the crops that revolutionized European tastebuds. Another imported high yielding crop, that reportedly saved Ireland from starvation, was the potato. However, there were still many food crops that resisted local cultivation and therefore had to be brought over from the colonies. Supply was notoriously irregular and rarely adequate to meet demands. It was not until the nineteenth century that supply became more reliable. This reliability owed much to the active colonization of new fertile lands in the East and the new discipline of economic botany.

In the nineteenth century, the political ideology of the times, the botanic gardens, and the colonial office functioned as an integrated framework, enforcing an economic structure whereby the East became the producer of raw materials for the West's industries. Indeed, this framework was a characteristic description of colonialism which involved, among other things, the establishment of plantations and the large-scale cultivation of economic plants, and the systematic transfer of economic plants from an area less productive or less conducive (either politically, economically, or scientifically) to a more productive and conducive one. Colonialism also entailed the need to coordinate and transfer labor from one colony to another in order to ensure the viability of a plantation or an agroeconomic project. Underwriting the success of the colonial plantations and agriculture-based economic projects were the many research oriented botanic gardens established throughout the colonies. The most prominent of these botanic gardens were the Calcutta Garden in India, the Peradeniya Gardens in Ceylon (Sri Lanka), and the Penang, Malacca, and Singapore Gardens in the Malay Peninsula, known then as *British Malaya*.

The Royal Botanic Gardens at Kew in London was the center for scientific research and coordination of the work of the botanic stations in the colonies. Kew's role was very well illustrated in the case of the discovery and cultivation of the cinchona tree – the medicinal tree from which the malarial medicine, quinine, was extracted. The discovery of cinchona involved a large army of field workers and researchers collecting and gathering seemingly irrelevant bits of information and materials, from every remote corner of the British Empire and beyond. The information and materials were sent to Kew for analysis. The discovery and eventual successful extraction of quinine, which turned out to be the most potent antidote for malaria, was a credit to Kew and its network of botanic gardens in the colonies. Indeed, quinine was not just an important scientific discovery; it also had important demographic and political effects. Through the control of malaria it saved the lives of countless colonial officials and their *coolies* (laborers) and made possible the large-scale colonial exploration and exploitation of Africa and the Far East.

Colonial Botany in the Malay Peninsula

Colonial botany came to the shores of the Malay Peninsula in the year 1822 with the establishment of the botanic garden in Singapore by Sir Stamford Raffles. The staff of the botanic garden was instrumental in overseeing the introduction and improvement of spice cultivation in the Straits Settlements. Indeed, in the Malay Peninsula *botany* was almost indistinguishable from *economy*. Whether the relationship between botany and colonial economy in the colonies had any influence in the formalization of economic botany back in the motherland is a difficult question to answer with certainty; but what is certain is that the colonial economy benefited much from the knowledge and expertise provided by economic botany.

Back in Britain, botany was given a boost following several developments, one of which was the appointment in 1841 of Joseph Hooker (1817–1911), far more widely known as a colonialist than as a botanist, as head of the Royal Botanic Garden at Kew. Kew was responsible for coordinating and supervising all the scientific research on economic plants and agriculture within the British colonial empire. It was under Kew's supervision that in 1858 new botanic gardens were established in Singapore superseding the one established by Raffles. In 1887 botanic gardens were also established in Penang followed soon after by another in Malacca.

Nowhere is the importance of Kew to British colonialism so clear as in the case of the transfer of the wild Brazilian rubber plant from Latin America to the Malay Peninsula. Initially, various species of wild rubber seeds were collected from the Amazon jungle and sent to Kew Gardens for study and analysis. Eventually a species, *Hevea brasiliensis*, was identified as promising and was transferred to the botanic gardens in Singapore. Under the supervision of the Singapore gardens which H. N. Ridley headed, politically backed by the colonial office,

and heavily financed by the Crown companies, experimental plantations were set up in various parts of the Malay Peninsula. The plantations turned out to be experimentally successful and, as anticipated, destined to become commercially successful too. At the turn of the twentieth century, with the advent of motor vehicles industry in Europe and America, rubber became one of the most important raw materials for the new industry. Rubber planting indeed became one of the most profitable colonial commercial ventures. Most importantly, rubber could only be found in abundant quantity and of high quality within the British Empire.

The transfer, identification, and eventual cultivation of economic plants would not have been successful without colonial botany equally recording a success in another related activity: taxonomical works. Indeed, one of the main tasks of the botanic gardens was taxonomical work closely associated with identifying economically and medically useful plants. The varieties of plant life in the tropics became a testing ground for the new system of classification. In the Malay Peninsula, the colonial taxonomical campaigns of identifying and naming tropical plants soon turned out to be an enormous task that almost overwhelmed the colonial scientists and their machinery. The variation of plant life in the tropics rendered it practically impossible for their taxonomists and the new taxonomy to start fresh from scratch. However, starting from scratch was the last thing that they had to do. Long before the arrival of the British, the natives had already classified most of the plants, especially the economically useful ones. More often than not, all the colonial taxonomist had to do was to refer to the local taxonomy and be creative. They eventually discovered that the local folk taxonomy was almost encyclopedic, encompassing the encounter of many generations of indigenous wisdom with the local flora.

Colonial Botany and Malay Ethnobotany

The encounter of the colonialists with Malay ethnobotany probably went as far back as the arrival of the first Europeans to the area. Tome' Pires, a Portuguese scholar and explorer, who visited Malacca during the Portuguese rule, noted the existence of a botanical tradition among the Malays. The Malay botanical tradition was described as being composed of a complex system of plant taxonomy and knowledge as well as the cultural-educational rituals associated with teaching and imparting the knowledge to successive generations.

The majority of the colonial botanists, with very few exceptions, were genuinely intrigued by the sophistication and mechanics of Malay plant taxonomy. They seemed to agree that the Malay taxonomy was much more than a fanciful accidental uttering of a primitive tribe oblivious to any sense of rationality or systematic thinking. In fact, in many ways it was comparable to the modern colonial system.

In the colonial scientific taxonomy, plants having the same kind of flower and fruit but which differ in details of size, shape, and color of the flowers, fruits, or leaves constituted a *genus*. A specific name came after the generic name either as an adjective qualifying it or as noun in the genitive case if the species was in honor of some person.

Colonial botanists noted that Malay folk taxonomy, on the other hand, was based on either the use or morphological characteristics of the plants, or at times both. Most economically useful plants were classified by their use, whilst medically useful plants and others were often classified by the morphology of their niche, leaves, fruits, or flowers. What was found as a pleasant surprise to many of the colonial botanists was the discovery that in many instances the colonial scientific taxonomy and Malay taxonomy shared common grounds. There were also considerable numbers of Malay taxonomical names that found no equivalents whatsoever with the colonial names. Names like *kedundung*, *Tinjau Belukar*, and *Puding* were morphological names referring to the chief characteristics of the respective plant. They could be either a reference to their growth habit, shape of leaves, flowers, fruits, or combinations of any of those. They did not correspond neatly to the modern colonial taxonomy.

However, in spite of that, Malay ethnotaxonomy was a tremendous aid to the colonial reclassification of plants in the tropical Peninsula to modern taxonomy.

Many of the taxonomical and other scientific findings were published in the *Kew Bulletin*. The Bulletin was not only important academically, but it was also a medium of communication and instruction between Kew and the imperial network of botanic stations. It played the dual role of a scientific medium and a channel for colonial interests, reflecting faithfully the nature of colonial scientific activities.

Colonial scientific activities in the Malay Peninsula, especially the botanical and the taxonomical exercises, were not just scientific per se; they were first and foremost an integral part of the colonial activity to sustain British colonialism. In short, they were by and for colonialism.

See Also

► Ethnobotany

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Combinatorics in Indian Mathematics

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Having prescribed the rule

$$C_n^r = \prod_{k=1}^{r} \frac{n-k+1}{k}$$

for the number of combinations of r things taken at a time from n things, Bhāskara II (AD 1150) remarked:

> This [rule] has been handed down [to us] as a general [method], being employed [for their

> own purposes] by the experts [of specific fields of study], namely, for the tabular presentation of possible meters in metrics, for the number of ways of opening ventilating holes, etc., and the diagram called Partial Meru in arts and crafts, and for the varieties of tastes in medicine. [But], for fear of prolixity, they are not explained here. (*Līlāvatī* 113–114)

It is impossible to tell exactly when and by whom this rule was formulated, but from ancient times Indian peoples have had a keen interest in arranging things in order in various aspects of human life and in theorizing in various areas of study.

The *Bhagavatī*, one of the 12 canonical books of the Jainas, counts by enumeration the number of all the possible cases when one person, two persons, three persons, etc., are distributed in the seven nether worlds.

Most books of Sanskrit and Prakrit prosody, such as the *Chandaḥsūtra* of Piṅgala (ca. AD 200?), *Vṛttajātisamuccaya* of Virahāṅka (between the sixth and the eighth centuries), *Jayadevacchandaḥ* of Jayadeva (before AD 900), *Chando'nuśāsana* of Jayakīrti (ca. AD 1000), *Vṛttaratnākara* of Kedāra (before AD 1000), *Chando'nuśāsana* of Hemacandra (ca. AD 1150), etc., devote one of their chapters (usually the last one) to "six kinds of ascertainment" (*ṣaṭpratyaya*), namely:

1. Spread (*prastāra*), to spread a list of all the possible variations of a given type of meter consisting of short and long syllables according to a certain method
2. Lost (*naṣṭa*), to find out a lost variation when its serial number in the list is given
3. Mentioned (*uddiṣṭa*), to calculate the serial number in the list when a particular variation is mentioned
4. Short-[and-long-]calculation (*laghu-kriyā*/*gala-kriyā*), to calculate the number of the variations in the list that have a given number of short or long syllables (for this purpose, a diagram called the Mount Meru-like spread (*meruprastāra*), equivalent to the so-called Pascal's triangle, is constructed)
5. Number (*saṃkhyā*), to calculate the number of all the variations in the list
6. Way (*adhvan*/*adhvayoga*), to calculate the space of writing materials required for writing down the list

A chapter on prosody in the *Nāṭyaśāstra* of Bharata (before AD 600), a dramaturgical work, and one in the *Agnipurāṇa* (ca. AD 800), a work on sacred traditions, also contain a section on these topics.

Four out of the six kinds of ascertainment, namely, spread, lost, mentioned, and number, were applied to the melody (combinations of seven notes) and the rhythm (combinations of a half, one, two, and three beats) in Indian music (Śārṅgadeva's *Saṅgītaratnākara*, ca. AD 1250), for which a diagram called Partial Meru (*khaṇḍameru*) was employed. This was also the case with the combinations of five subcategories taken severally from five categories of "carelessness" (*pramāda*) when they contain different numbers of subcategories, in Jaina philosophy (Nemicandra's *Gommaṭasāra*, ca. AD 980).

Medical treatises such as the *Carakasaṃhitā* (ca. AD 100) and *Suśrutasaṃhitā* (ca. AD 200) treated combinations of the six basic tastes (*rasa*) and of the three humors (*doṣa*) of the body. Varāhamihira dealt with the problem of combinations of nine and sixteen basic perfumes in the *Bṛhatsaṃhitā* (ca. AD 550). He gave a simple method for obtaining ${}_nC_r$ in tabular form which is essentially the same as Pascal's triangle.

Indian mathematicians prior to Bhāskara, too, are known to have been interested in these problems of combinatorics. Brahmagupta devoted one whole chapter consisting of 19 (or 20) stanzas of his astronomical work, *Brāhmasphuṭasiddhānta* (AD 628), for combinatorics related to Sanskrit prosody. The problem of tastes was taken up by the mathematician Śrīdhara in his *Pāṭīgaṇita* (ca. AD 750). Mahāvīra treated the six kinds of ascertainment of Sanskrit prosody as well as tastes in his mathematical treatise, *Gaṇitasārasaṃgraha* (ca. AD 850).

In addition to the traditional rule for combination mentioned above, Bhāskara gave six rules for permutations concerning sequences of numerical figures in a chapter called "nets of numbers" (*aṅkapāśa*) of his famous *Līlāvatī*. However, it is

Nārāyaṇa who for the first time treated various problems of permutation and combination, including the system of "spread-lost-mentioned," of different areas systematically from the viewpoint of mathematics with the help of variously defined sequences of numerals. Chapter 13 entitled "nets of numbers" of his mathematical treatise, *Gaṇitakaumudī* (AD 1356), consists of about 100 stanzas for rules of combinatorics and 45 for examples.

See Also

- ▶ Bhaskara I
- ▶ Brahmagupta
- ▶ Mahāvīra
- ▶ Nārāyaṇa Paṇḍita
- ▶ Śrīdhara
- ▶ Varāhamihira

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Combinatorics in Islam

Ahmed Djebbar

Among the factors which influenced mathematics in Arab-Islamic civilization was a cultural life which fostered, particularly between the ninth and twelfth centuries, rich interaction between the different intellectual activities of the time.

Taken in a general sense as a study of configurations in one-, two-, or three-dimensional spaces, combinatory analysis had its beginnings in early studies in music, chemistry, astrology, and especially in metrics and Arabic linguistics. From the ninth century on combinatory processes asserted themselves in truly mathematical disciplines like algebra, astronomy, and trigonometry.

Combinatory Practices in Nonmathematical Fields

In music, many works contain a study of the combinations of sounds and rhythms, for example, the Rasāʾil (Epistles) of the Ikhwān al-ṣafāʾ (Brethren of Purity, tenth century) and the *Kitāb al-mūsīqā al-kabīr* (Great Book on Music) of al-Fārābī (ninth century). In the field of chemistry, as early as the eighth century, ► Jābir ibn Ḥayyān introduced combinatory arguments in his theory of balance, which was based on the principle that everything is a combination of numbers. Jābir goes so far as to identify the language, i.e., the combination of words, in chemistry which he considers to be a morphology of metals.

In astronomical astrology, the conjunctions of the seven planets known at that time played an important role in predicting events. One needed to know the number of conjunctions which corresponded with the number of combinations of seven elements two times two, three times three…seven times seven. There was a great need to construct configurations by manipulating numbers or letters. Many mathematicians worked on this problem trying to invent processes of construction and new types of magic squares, for example, ► Thābit ibn Qurra (d. 901), Abū'l-Wafāʾ (d. 997), Ibn al-Haytham, ► Ibn Munʿim (d. 1228), and ► Ibn al-Bannāʾ (d. 1321).

In the field of Arabic poetry, it was al-Khalīl ibn Aḥmad (d. 791) who originated research on meter. He began by deriving a superficial structure of Arabic verse (which also serves for prose). Then he derived an underlying structure based on ten measures which, in combination, provided the five fundamental meters. In turn, these meters provided other meters to Arabic poetry thanks to a purely combinatory operation, circular permutation.

In the field of Arabic prose, there is even more interesting information about combinatory practices. As early as the eighth century, al-Khalīl undertook an analysis of the structures of the Arabic language and attempted to develop a theory based on the results of his investigations by studying the constitution of the roots of the language from the 28 letters of the alphabet, and then the composition of words from those roots. To that end, he calculated combinations, without repetitions, of letters two by two, three by three, four by four, and five by five, in order to determine the numbers of roots of two to five letters in the language. The results of his calculations, without any explanation, appear in his book *Kitab al-ʿayn*. After him, a long tradition was established in this field, but the combinatory aspects have not been systematically studied.

That being said, the examples cited above are really too sparse and isolated to prove any continuity in combinatory practices. In particular, we have not yet found anything which demonstrates the beginning of the mathematization of these combinatory practices in the Muslim East or in Andalusia before the twelfth century.

Combinatory Practices in Mathematics

Combinatory practices in the field of mathematics prior to the twelfth century were relatively modest and concerned only two disciplines, astronomy and algebra.

In astronomy, for example, there is the book of Thābit ibn Qurra, *Al-shakl al-Qaṭṭāʿ*, in which combinations occur, two by two, in six sizes occurring in the formula fixed for the secant figure. In his book, *Maqālīd ʿilm al-hayʾa* (Keys to the Science of Astronomy), ► al-Bīrūnī also uses small combinatory results for the purpose of determining the unknown elements of a spheric triangle as a function of the known elements.

In algebra, there are two works which contain certain aspects of combinatorics. The first, the *Kitāb al-ṭarāʾif fi'l-ḥisāb* (Book of Rare Things in the Art of Calculation) by ► Abū Kāmil (d. 930), deals with the resolution of certain systems of indeterminate equations, stated in the form of problems of birds, the aim being to enumerate, for each system, all the possible solutions. The second work is the *Kitāb al-Bāhir* by as-Samaw'al (d. 1175) on algebra, its objects and its instruments.

We have, as yet, no way of proving that these combinatory practices from within the

mathematical tradition gave rise to any real research in the field between the ninth and the twelfth centuries, and in instances where research did occur, we do not know the results. In any case, it was not the combinatory elements encountered in mathematical problems which inspired the mathematicians of the Maghreb who became involved in combinatorics. It was the tradition of linguistics and lexicography which was the basis of their research.

Ibn Mun ʿim

The oldest mathematical work from the Maghreb which deals with combinatory problems is the *Fiqh al-ḥisāb* of ► Ibn Munʿim, a scholar originally from Andalusia, living in Marrakesh in the Almohad era. To our knowledge, his book was the first in the entire history of mathematics to have devoted a whole chapter to this type of problem and to have stated them and solved them according to a common procedure.

Combinatorics After the Thirteenth Century

In the second half of the thirteenth century or the beginning of the fourteenth, another Maghrebin mathematician, ► Ibn al-Bannāʾ, took up some of the results of Ibn Mun ʿim in at least two of his works, the *Rafʿ al-ḥijāb* and the *Tanbīh al-albāb*. In the latter work, he notes only a table of combinations from Ibn Mun ʿim without giving exact references, but he explicitly lays claim to the demonstration of a result long attributed to Pascal (d. 1662) which gives C_n^p as a function of C_n^{p-1}, thus allowing the calculation of the combinations two times two, three times three, etc., of a certain number of objects, using the arithmetical formula:

$$C_n^p = \frac{n(n-1)\cdots(n-p+1)}{1\cdot 2\cdot 3\cdots p\cdot(p-1)}$$

which today takes the form of

$$C_n^p = \frac{n!}{p!(n-p)!}$$

In the same spirit, he deduced the expression of arrangements without repetition of a certain number of objects, after having calculated the number of their permutations.

It is important to point out that, at the same time, in the East, the mathematician al-Fārisī (d. 1321) identified the values of the different combinations of the elements of the arithmetic triangle of ► al-Karajī and used them to establish a theorem of the theory of numbers such that one can determine the number of divisors belonging to a certain whole. Unfortunately, we do not know if this contribution of al-Fārisī spread throughout the East nor can we affirm that it was known in the Muslim West.

However that may be, we can discern two significant processes from Maghrebian writings after Ibn Mun ʿim. First, there occurred the extension of the field of application of formulas and of combinatory reasoning. This field was no longer concerned just with the elements of an alphabet, since that became an abstract model operating in different mathematical fields: in astronomy, with the reformulation and enumeration of compound ratios occurring in spheric trigonometry; in geometry, with the classification of figures and the enumeration of all the equations one can deduce; and finally in algebra, with the enumeration of systems of equations (the work of Ibn Haydūr (d. 1413) and of equations of a certain degree greater than three (the work of the Egyptian Ibn alMajdī, d. 1447, in his commentary on the *Talkhīṣ* (Summary) of Ibn al-Bannāʾ).

In the second place, there was a taking account of enumeration in general, in very different fields not always related to mathematics. The most typical case is that of Ibn al-Bannāʾ, who devoted part of his work *Tanbīh al-albāb* to these types of problems: the enumeration of different cases of possible inheritances when the heirs are n boys and p girls, the enumeration of prayers to be said according to the exigencies of Malekite ritual in order to compensate for having forgotten other prayers,

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and the enumeration of all the possible readings of the same sentence according to the rules of Arabic grammar.

The presence of the same combinatory vocabulary in the works of different authors and the fact that none of them laid explicit claim to their results reinforces the characters of continuity of combinatory practices, a continuity made possible, probably, by the persistence of this new chapter in the teaching of certain professors of that time.

However, if to our eyes this new material and these new instruments seem objectively to be of a piece, we do not know to what degree those who contributed to their formulation were conscious of them or what importance they held in *their* eyes.

The reasons for this are to be found in several places at once: the state of the society itself and the nature of its activities and preoccupations which did not allow for the significant development of combinatorics; the absence of local or regional institutions responsible for renewing programs and imposing, and then perpetuating, the teaching of new ideas; and the imprint of certain specialists whose authority influenced at certain moments the content of scientific teaching, fixing it or simplifying (or deleting) certain theoretical developments and certain chapters. At least that is what ► Ibn al-Bannāʾ implies in his *Rafʿ al-ḥijāb* and what ► Ibn Khaldūn confirms in his *Muqaddima* (Prolegomena), writing about the abandonment of theoretical problems and the perpetration of a more utilitarian mathematics.

See Also

► Algebra in Islamic Mathematics
► Al-Karajī
► Ibn al-Bannāʾ
► Ibn Khaldūn
► Ibn Munʿim
► Ikhwān al-Ṣafāʾ
► Magic Squares in China
► Number Theory in Islamic Mathematics

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Comet and Meteorite Traditions of Aboriginal Australians

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Introduction

This research contributes to the disciplines of cultural astronomy (the academic study of how past and present cultures understand and utilise celestial objects and phenomena) and geomythology (the study of geological events and the formation of geological features described in oral traditions).

Of the hundreds of distinct Aboriginal cultures of Australia, many have oral traditions rich in descriptions and explanations of comets, meteors, meteorites, airbursts, impact events, and impact craters. These views generally attribute these phenomena to spirits, death, and bad omens. There are also many traditions that describe the formation of meteorite craters as well as impact events that are not known to Western science.

Comets

Bright comets appear in the sky roughly once every 5 years. These celestial visitors were commonly seen as harbingers of death and disease by Aboriginal cultures of Australia. In an ordered and predictable cosmos, rare transient events were typically viewed negatively – a view shared by most cultures of the world (Hamacher & Norris, 2011). In some cases, the appearance of a comet would coincide with a battle, a disease outbreak, or a drought. The comet was then seen as the cause and attributed to the deeds of evil spirits. The Tanganekald people of South Australia (SA) believed comets were omens of sickness and death and were met with great fear. The Gunditjmara people of western Victoria (VIC) similarly believed the comet to be an omen that many people would die. The coincidence of a comet and a drought led the Euahlayi people of New South Wales (NSW) to believe comets were evil spirits that sucked the water from clouds, causing the drought. The tail of the comet was a large family that consumed the water from the river.

Other Aboriginal groups gave significance to the tail of a comet resembling smoke. Aboriginal communities of the Talbot district (VIC), Cape York (QLD), and Bentinck Island in the Gulf of Carpentaria (QLD) made this association – one shared with the Maori of Aotearoa (New Zealand). Groups in the Central Desert of the Northern Territory (NT) believed comets represented celestial spears thrown by spirits or ancestors in the sky, including the Pitjantjatjara, Kaitish, Luritja, and Arrernte.

Meteors

Views of meteors across Aboriginal cultures are many and diverse, but most relate to death and evil spirits (Hamacher, 2011; Hamacher & Norris, 2010). A frequent interpretation is that meteors were the spirits of the recently deceased. In Wardaman traditions (near Katherine, NT), when a person dies, his spirit ascends into the sky and passes through the star *Garrndarin* (Spica), becoming a star of its own. It was looked after by the Rock-Cod star *Munin* (Arcturus) before falling back to Earth as a meteor. The star-spirit fell into a stream, where the earthly Rock-Cod looked after it again. The spirit then pursued a potential mother and entered her to be reincarnated as a baby.

Across northern Australia, meteors are seen as the fiery eyes of celestial serpents (sometimes called the Rainbow Serpent). The Tiwi people of Bathurst and Melville islands north of Darwin, NT, see meteors as the *Papinjuwari* – evil spirits with long claws that steal the hearts of babies. In the Yolngu traditions of Arnhem Land (NT), a similar spirit is called *Namorrorddo*, and in Lardil traditions of Mornington Island (QLD), it is called *Thuwathu*.

Meteor traditions also involved war. Aboriginal groups in northern QLD followed the trails of meteors, believing the falling stars would lead them to enemy warriors. The Ngarigo people of NSW believed a meteor pointed to the direction of a group preparing for war. The Wathi-Wathi people of the Murray River region in VIC perceived meteors as the path of a nulla-nulla (a short spear) in the sky. Similarly, Arrernte revenge rituals in the Central Desert (NT) involved throwing a small spear filled with evil magic in the direction of the intended target. If a meteor appeared, it signified the death of the person.

Impact Events

Oral traditions of Aboriginal groups across Australia describe fiery stars falling from the sky with a roar, striking the land and causing death and destruction. All of these accounts, except for Henbury (described below), do not coincide with impact sites known to Western science (Hamacher & Norris, 2009).

The Weilan people of north central NSW tell of a large star that fell to Earth, lighting up all of the surrounding land. A similar story is recounted from the Aboriginal people of Wilcannia in northwestern NSW who describe a large fiery star that rumbled and smoked as it fell from the

sky, crashing into the ground in the Darling riverbed northeast of Wilcannia at a place called *Purli Ngaangkalitji*. A deluge followed the impact. It is not certain if these stories are related, but no known impact sites are located in NSW.

Yuin traditions from the Shoalhaven region near Nowra, NSW (south of Sydney), describe an impacting meteor shower and airburst. In the story, the sky heaved and many stars fell to the Earth, flashing in the sky. A large reddish mass burst in the air, causing a deafening roar and scattering debris across the region, leaving burnt holes in the ground. A Gurudara story from east of Darwin, NT, tells how a bright star named *Nyimibili* fell from the sky onto the camp near the Wildman River, burning all of the grass and trees.

Some published research suggests that impact rates are higher than currently predicted by scientists and that large impacts in the ocean have occurred in recent times (<1,000 years), causing huge tsunamis to strike coastal Australia and New Zealand. These claims are circumstantial and have been refuted, but remain a controversial topic in modern studies of cultural astronomy and geomythology.

Meteorite Craters

Aboriginal people have oral traditions that relate to the Gosses Bluff crater (NT), Liverpool crater (NT), Wolfe Creek crater (WA), and the Henbury crater field (NT) (Hamacher & Goldsmith, 2013). The Liverpool crater, which is 1.6 km wide and formed over 500 million years ago, is called *Yingundji* in the Kunwinjku language of eastern Arnhem Land. It is believed to be the nest of a giant catfish, and rock art depicting catfish was found in caves along the crater wall.

The Wolfe Creek crater, located in the eastern Kimberley region of WA, was formed 300,000 years ago and is 900 m wide. It is called *Kandimalal* in the local Jaru language, and there are several stories about how the crater formed (Goldsmith, 2000). These include a being that was digging for yams, a Rainbow Serpent emerging from the ground, and a star falling to the Earth. Some traditions seem to have incorporated the views from Western scientists working in the area, as attested by an Elder who claimed the star story was "white man's story" (Reeves-Sanday, 2007).

Gosses Bluff crater, west of Alice Springs (NT), is 22 km wide and heavily eroded, having formed about 142 Ma ago. What remains is a ring-shaped mountain range, 5 km in diameter and 150 m in height. The Western Arrernte people call it *Tnorala*. In Arrernte traditions, a group of eight women were going to took the form of stars to have a ceremony in the Milky Way. One of the women set her baby in a wooden basket called a turna. As she danced in the ceremony with the other women, the baby rolled off the Milky Way and fell to the Earth. The impact of the baby and the turna drove the rocks upward, creating the ring-shaped mountain range. The turna can be seen in the sky as the constellation Corona Australis (the Southern Crown). The baby's parents - the morning star and evening star - continue to search for their baby.

One of the youngest impact sites in Australia is the Henbury crater field, south of Alice Springs. It formed when a meteoroid broke apart in the atmosphere and created 13 craters covering a square kilometer. The impact occurred <4,700 years ago and was probably witnessed by Aboriginal people. Oral traditions collected in the 1930s describe the crater field as a place where a fire devil came from the sun and ran down to the Earth, forming the craters. The spirit burned and ate the people for breaking sacred laws. Aboriginal people would not collect water that pooled in the craters for fear the fire devil would fill them with iron.

Meteorites

Some Aboriginal people used meteorites as axe heads, which were generally viewed with reverence as sacred objects. Aboriginal people were "deadly afraid" of meteorites from the Tenham meteorite fall of 1879 in western QLD. There is evidence of Aboriginal people transporting meteorites long distances, but the reasons for this are

not known (Bevan & Bindon, 1996). In the early twentieth century, interest in meteorites by white Australians prompted Aboriginal people to collect meteorites and tektites for sale to interested parties. Tektites were commonly used as surgical tools and ritual implements (Baker, 1957; Edwards, 1966).

Conclusion and Future Directions

Aboriginal Australians have complex and varying perceptions and traditions regarding comets, meteors, meteorites, and impact events across Australia. New research is identifying additional oral traditions about these phenomena and ways in which these phenomena were represented in ceremony and sacred law, which contributes to the growing body of knowledge about Aboriginal astronomical traditions. These traditions may benefit the field of geomythology by leading scientists to impact sites and meteorite falls that are currently unknown to Western science. This research is now expanding to the Melanesian islander cultures of the Torres Strait (who are indigenous to Australia) that have many traditions, ceremonial dances, and songs related to comets and meteors.

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Comets and Meteors in the Islamic World

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The Muslim records on the appearance of comets during the premodern period are fairly extensive, but they are scattered throughout the entirety of Arabic and Farsi literature rather than localized. There is no unified term for comets during the premodern period: names such as *najm dhū dhū'aba*/*dhūa'ib* (a star with locks of hair), *najm dhū dhanab* (a star with a tail), or the same combinations with *kawkab* (planetary body) are interchangeable inside the literature. Eventually in Arabic, *najm* came to mean "a fixed star" while *kawkab* "a planetary body" but there are plenty of exceptions to this rule.

In general, the appearance of comets was a disturbing event, and they were usually considered signs of the end of the world. As such, comets were often ignored in standard astronomical treatises since they did not conform to the Ptolemaic patterns of fixed and moving stars (planets). However, unlike in other cultures, there is no evidence that the appearance of comets in the Muslim world actually caused any sort of apocalyptic movement or triggered any form of social disturbance. Materials concerning the sighting of comets are easily divided into several groups:

1. The earliest period of Islam (630–750): Most of the sightings from this period are recorded in Christian chronographies (frequently associated with the astronomer Theophilus of

Edessa [d. 785]) or are associated with the deaths of the major Muslim figures from this period and are therefore questionable in their historicity.
2. High Islamic period (750–1250): There are extensive and frequently detailed descriptions of comets from this period. Although one cannot say that the Muslim material is as extensive as that of the Chinese from the same period, when one gathers together all of the comet sightings, most of the major comets are attested.
3. Late Islamic Period (1250–1811): Comet sightings continue after the Mongol invasions in Persian, Ottoman, and late Arabic histories. However, these sightings are few and far between and usually have nothing of the detail contained in the high Islamic period sightings. The latest comet sightings recorded are from 1811.

Gary Kronk in his *Cometography* (1999) has stressed the importance of the Arabic-language materials for the study of historical comets as these sightings are often unique outside of the Chinese sightings, most especially for the period 750–1000 when attestations in European sources are weak. However, one major difference should be noted between the Chinese and Arabic materials: in the vast majority of cases, the Arabic materials are anonymous and do not give us any sense of who made the sighting, where it was made, and more often than not, when it was made. These problems make correlating the sightings problematic. Kronk notes that when the dates of comet sightings can be checked against the Chinese, the Arabic sightings are usually slightly earlier (Cook, 132, personal communication). We must assume, therefore, that the sightings are not necessarily those of astronomers, but were based upon local and popular sources.

Religious Beliefs About Comets and Meteors

Comets are not mentioned in the Qurʾān, although perhaps they are alluded to in Q 53:1, 81: 1–2, and 82:1–2. Beliefs concerning the importance of comets could be either positive or negative. For example, Jalal al-Din al-Suyūṭī (d. 1505) includes the tradition ascribed to the Prophet Muhammad: "When the star (*najm*) rises, then malady will be lifted from every land" (al-Suyūṭī 21 [no. 49]). However, al-Baghdādī [d. 1071] 27 notes that this could be the Pleiades. He also includes a longer apocalyptic tradition as a conversation between Ibn ʿAbbās [d. 658], the forefather of the ʿAbbasid Dynasty, and Ibn Abī Malika, in which the former said to the latter: "I did not sleep last night." The latter said, "Why?" Ibn Abī Malika answered "They have said that the star with a tail (*kawkab dhū dhanab*) has risen, and I feared that the Smoke [of the Judgment, Q 54:1] would come by night" (al-Suyūṭī 21 [no. 50]). Comets are usually listed as part of the signs of the end of the world.

Popular beliefs associated shooting stars with the nonhuman jinn (Q 72:8–9) and held that the flameouts of the stars were caused by jinn's attempts to penetrate the heavens and being repelled by God. Traditionally, the jinn would use the shooting stars and meteors to listen into the events transpiring in heaven. The appearance of comets was often mixed in with these beliefs, being seen as more powerful and enduring than shooting stars. Astrologers and other mystics utilized materials supposedly from either Daniel or Enoch (Idris) and sought to make predictions based upon the zodiac signs in which a comet could appear (al-ʿAskari, n.d., pseudo-Idris, 53–55). However, because of their unpredictability, comets do not often appear in astrological materials.

Astronomical Explanations of Comets

Muslim Arabic-language astronomical explanations of the appearance of comets relied heavily upon classical and late-antiquity Greek interpretations of their function. In general comets were considered to be a phenomenon of the sublunar region and should not be associated with the unchanging celestial region (Ragep, ii, 384, citing al-Ṭūsī; also al-Khwārizmī 195).

Later, the well-known philosopher and Aristotelian Ibn Rushd (Averroes) (d. 1198) detailed the positions of a number of Greek philosophers and astronomers in his *Talkhīṣ*, and after refuting the idea that comets could only appear from the north through his personal observation states:

> Comets (*kawakib dhū wat al-dhua' ib*) in their totality are among the planets (*kawakib*) which are part of the heavenly body, nor are their locks just a phase of the moon because of the dampness, as it proceeds that the comets are possessed of a fiery nature—both the comets and their locks together. This is because when this fire is an accident, not close to any of the planets (*al-kawakib al-sayyara*). If the locks were composed of a phase of the moon accidental from the light of the planets close by or from the vapor close by burning, then the light of the planets would connect to the light of this vapor, and it would seem elongated. But the locks which are burning smoke do not reach the planets, even though they seem to because the light of the planets is connected with the light of this vapor, and thus it seems as if it is one elongated light. (Ibn Rushd [47–48, no. 43])

Ibn Rushd's general conclusion, therefore, is that comets are similar to shooting stars, but that they are comprised of the phases of the moon together with burning vapor. Much more detail can be found in Heidarzadeh (2008, pp. 28–31), who summarizes a wide range of Islamic materials and places them within their classical context.

Descriptions of Comets and Meteors

The historical material concerning comets begins in 760 with the (probable) sighting of Halley's Comet during that year (Nu›aym 132). There are several sightings of a questionable nature prior to 760 to mark the deaths of prominent figures (Muḥammad [d. 632]; Abū Bakr, first caliph [632–634]; and others), but from 760 onward until the Mongol invasions (1256–1261) the cumulative Arabic-language historical record has approximately 85 sightings of comets. Most of this material is to be found in the large chronographic histories of Ibn al-Athir (d. 1232) and Ibn al-Jawzi (d. 1200). An example of these sightings, from 1066, will suffice:

> In the first tenth of Jumada I [31 Mar.-9 Apr.] a star appeared with long locks of hair in the direction of the east. Its length was six degrees (*dhira'*), while it was spread across the center of the sky. It stayed until the seventeenth of the month [16 April], and then disappeared and then again at the end of the month, at the setting of the sun, a star appeared whose light revolved around it like that of the moon. People were frightened and were very disturbed. When the night grew dark, it had many locks of hair to the south, and it stayed ten days and then disappeared. (Cook 144, no. 69)

This is most probably the appearance of Halley's Comet in 1066, an appearance corroborated by another sighting in the *History of the Patriarchs of the Egyptian Church* (in Arabic).

Alongside the historical comet sightings, there are approximately 50 records of meteors, either in showers visible in the heavens or as meteorites striking the earth. Usually the latter are described in formulaic terms: "[in 918–919] A huge star fell and its light was very strong, it was great and broke up into three pieces. At that point a sound like that of loud thunder when it fell, but there were no clouds in the sky" (Cook 139 [no. 30]). Mention of shooting stars or meteors after the Mongol invasions are comparatively rare and persist mostly in the Yemeni chronicles.

Records of comets and astronomical phenomena drop dramatically after the Mongol invasions, and although they never completely disappear, they become perfunctory. Persian and Ottoman chroniclers infrequently note the appearance of comets (e.g., the comet of 1618–1619 is recorded by the Ottoman chronicler Naima: "There appeared one evening in the heavens a bright pillar or column which shone like a comet, the appearance of which occasioned among the people a variety of conjectures" (trans. Fraser 464)). Comet descriptions are especially frequent in the more outlying regions of the Muslim world, for example, Yemeni chronicles, such as that of Ibn al-Qasim (750–806), are especially rich in comet sightings for the period of the 1600s and 1700s as are those from Western Africa (such as Timbuktu).

The last significant notes of comets in the Arabic historical literature are from 1811, one from the last of the medieval chronographers, al-Jabarti (d. 1822): "During this month a comet appeared in the north between Ursa Minor and Ursa Major, its head in the west and its long lance-like tail climbing to the east. It was visible every night. The people watched it, talked about it, and questioned the astrologers about it. They speculated about its portent and what bloody battles it foretold. It was visible for about 3 months, diminishing somewhat in size. It went off toward the south near Aquila" (Jabarti in Philipp and Perlmann, iv, 189).

It is analogous to the record of Haydar al-Shihabi (d. 1835?) in Lebanon for the same year: "During this year a star with a tail appeared in the heavens, and the first part of its appearance was on the 4th [no month noted] and it continued to appear every day just before the morning in the area of Ursa Minor, and stayed until the end of the summer, and then disappeared and did not leave any trace which would point to its appearance" (Shihabi, 573).

Additionally, comet sightings are to be found in the apocalyptic literature from the period of Nuʿaym b. Hammad al-Marwazi (d. 842), who mentions the passing of Halley's Comet in 760 (Nuʿaym 132-3) and alludes to several other datable comets. In general, comets in the apocalyptic literature are seen as a sign of the end of the world, but after these initial prophecies, most of the material is too general to be dated.

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Compass

Julian A. Smith

The origin of the magnetic compass is obscure. Medieval and Renaissance European compasses have been analyzed in detail, but until recently

little work has been done on their history in non-Western cultures. Most modern accounts place the birth of the magnetic compass in ancient China, but its inventors are unknown, its development unclear, and historians are divided over whether its later appearance in the West was independent, or borrowed from China through overland or Arabic maritime intermediaries.

The Chinese compass seems to have been derived from a "south controlling spoon" (*si nan shao*) carved from lodestone (magnetite) and used in the early diviners' boards the Han Dynasty (202 BCE-AD 220). Just as in ancient Greece, Chinese philosophers were first aware of magnetic attraction; the ability of the lodestone to pick up iron was mentioned in the *Lü Shi Chun Qiu* (Master Lu's Spring and Autumn Annals, third century BCE), the *Lun Heng* (Discourses Weighed in the Balance, AD 83), and a host of other Chinese annals between the third century BCE and the sixth century AD. The discovery of magnetic directivity (the tendency of magnets to point north and south) made the lodestone particularly important in geomancy and divination. Historian Joseph Needham argued that this was known publicly by the first century AD, and may have been a secret of court magicians as early as the second century BCE.

Between the first and sixth centuries AD, Chinese scholars discovered that magnetic directivity could be induced in small iron needles by stroking them on lodestones. These needles, when floated in bowls of water (sometimes hidden inside carved wooden fish), would then guide Chinese navigators by pointing to the north and south; these early "wet compasses" were the first type. The second variety, a "dry compass" consisting of a needle mounted on a pivot (often concealed inside a wooden turtle), was developed much later (early twelfth century). Chinese encyclopaedias such as the *Taiping Yulan* (Taiping Reign-Period Imperial Encyclopaedia) also mention "dry" compasses made by suspending a magnetic needle on a silk thread.

Chinese physicists may also have been first in discovering magnetic declination. The fact that the compass does not point exactly to the geographic north, but rather to the magnetic north a few degrees away, was mentioned in philosopher Shen Gua's *Meng Qi Bi Than* (Dream Pool Essays) in 1088 AD. He says the compass needle "always inclines slightly to the east." Knowledge of this effect was extremely important for ocean navigation. Chinese knowledge of declination goes back to the late Tang period (eighth-ninth centuries AD).

The development of the magnetic compass in India is highly uncertain. According to some scholars, the compass is mentioned in fourth century AD Tamil nautical books; moreover, its early name of *maccha-yantra* (fish machine) suggests a possible Chinese origin. In its Indian form, the wet compass often consisted of a fish-shaped magnet, floated in a bowl filled with oil.

The earliest references to the magnetic compass in Europe appear in the grammatical and philosophical treatises *De Nominibus Utensilium* and *De Naturis Rerum* of English monk Alexander Neckam (1157–1217), French poet Guyot de Provins' (fl. 1184–1210) *La Bible*, and the *Historia Orientalis seu Hierosolymitana* of French preacher Jacques de Vitry (ca. 1165–1240). Based on these sources, historians have dated the European appearance of both dry and wet compasses to the middle of the twelfth century.

Among Arabic sources, the earliest descriptions of the magnetic compass occur in the thirteenth century. A Persian collection of stories, the *Jāmiʿ al-Ḥikāyāt* (ca. 1232) of Muḥammad al-ʿAwfī says that sailors navigate using a piece of iron rubbed by a magnet, and the 1282 lapidary of Bailak al-Qabajaqi, the *Kanz al-Tijar*, mentions a wet compass seen in 1242. Some of these early treatises discuss the use of fish-shaped compass needles among Islamic navigators in the Indian Ocean, suggesting a possible borrowing from Indian sailors; but it is also possible that Arabs got the compass from Europeans (scholars arguing this hypothesis often point out the Arabic word for compass, *al-kunbas*, appears to come from Italian roots). Much more research needs to be done before this argument can be settled.

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Computation: Chinese Counting Rods

Lam Lay Yong

The basic questions in the study of arithmetic in any civilization are: how did the people add, subtract, multiply, and divide, and what were the notations and media that were used to perform these operations.

The ancient Chinese used ▶ bamboo sticks or animal bones to count. The first five numbers were tallies in the following form:

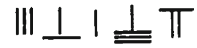
The representations for six, seven, eight, and nine were as follows:

The horizontal rod represented the quantity five.

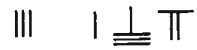
It is easy to imagine how these rod numerals were handled for the addition or subtraction of small numbers such as two plus five or nine minus two. In the case of the addition of, for example, six and seven, the three vertical rods were grouped together and the two horizontal rods representing two fives were replaced by a single rod positioned horizontally to the left of the three vertical rods. The sum, 13, was expressed in the following form:

In this manner, a place value notation was created; the tens' place was to the left of the units' place. The nine numerals that could occupy this place were similar in idea to the nine numerals shown above but had a significant difference: the vertical rods were turned into horizontal ones and the horizontal rods were turned into vertical ones. They were of the following form:

The notion of place values was then extended to express larger numbers. The first set of nine numerals occupied positions whose place values were units, hundreds, ten thousands, and so forth; the second set of nine numerals occupied positions whose place values were tens, thousands, hundred thousands, and so on. For example, the rod numeral for 36,187 appeared as



and the rod numeral for 30,187 appeared as



which revealed that the thousands' place was empty.

Any number, however large, thus could be represented by the rod numeral system, which used a place value notation with ten as base. The rod numeral system was essentially a computing mechanism; the results of the calculation were recorded in the written numbers.

The rods were used for reckoning in the fifth century BCE. According to *Qian Han shu* (Standard History of the Western Han Dynasty), they were cylindrical bamboo sticks, 0.1 *cun* (approximately 0.231 cm) in diameter and 6 *cun* long. They were carried in a hexagonal bundle made up of 271 pieces. Computation was

performed on a flat surface such as a table or a mat. By the sixth century AD, the rods were shorter in length and square in cross-section. During the Tang Dynasty (AD 618–907), it was quite common for officials, astronomers, engineers, mathematicians, and others to carry their bundles of rods wherever they went. Besides animal bones and wood, the rods could be carved from horn, ivory, or jade.

► *Sun Zi suanjing* (The Mathematical Classic of Sun Zi) written aiiiuiul AD 400 is the earliest existing work to have a description of the rod numerals. It also gives detailed descriptions of how multiplication and division were performed. The step-by-step procedures are the same as the earliest known methods of multiplication and division using Hindu-Arabic numerals, which were described by Muḥammad ibn Mūsā ► al-Khwārizmī in his book on arithmetic and by Abū al-Ḥasan Aḥmad ibn Ibrāhīm ► al-Uqlīdisī in *Kitāb al-Fuṣul fī al-Ḥisāb al-Hindī*. This fact together with other evidence supports the thesis that the Hindu-Arabic numeral system has its origins in the Chinese rod numeral system.

Just as the Hindu-Arabic numeral system provided the mainstay and impetus for the growth and development of our arithmetic and algebra, the rod numeral system provided the same support for the development of mathematics in ancient and medieval China.

The process of division with rod numerals resulted in an important notation for the expression of a fraction. For example, the notation for four-fifths is

This is the same as the notation for the common fraction in Hindu-Arabic numerals which also originated from the earliest method of division with numerals. The use of this notation enabled an extensive study on operations with fractions – a subject with which other ancient civilizations had difficulties that were frequently insurmountable.

With the concept of the rod numeral system ingrained in their minds and using the rods as the medium of expression, the ancient Chinese developed arithmetic and algebra. The problems in *Jiu zhang suan shu* (Nine Chapters on the Mathematical Art) (ca. AD 100) show that they were able to solve problems involving fractions, the Rule of Three, proportion, areas and volumes, square roots and cube roots, the Rule of False Position, sets of simultaneous linear equations, and negative numbers.

For numerous centuries the rod numeral system played a dual role: in calculation and in the development of mathematics. It aided the progress of the Chinese civilization till the Ming Dynasty (1368–1644) when it was gradually replaced by the abacus as an instrument for computation. Mathematics flourished from the firm foundation depicted in *Jiu zhang suan shu* and reached its peak in the thirteenth century. When the rod numerals became outmoded and fell into disuse, mathematics also underwent its period of decline and transition.

See Also

► Abacus
► Algebra in China
► al-Khwārizmī
► Al-Uqlīdisī
► Shushu Jiuzhang
► Sun Zi

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Computing Science in Ancient India

Subhash Kak

India's romance with numbers can be seen in the mention of large numbers up to 10^{19} in the Black Yajurveda. The sources for mathematical computing in India in the early phase are the Vedic books including the Brāhmana texts, the *Śulbasūtras* (texts on altar geometry), *Jyotisha* (astronomy), the *Chandahśāstra* (Pingala's book on prosody), Pānini's grammar, the *Nātya Śāstra* (Bharata Muni's text on music, drama, and dance), and nonmathematical texts such as the *Mahābhārata* and diverse *śāstras* (scientific and philosophical texts).

The Indian approach to the world was classificatory and computational. In astronomy, an attempt was made to reconcile the motions of the sun, the moon, and the planets that required periodic corrections. In grammar, the most economical rules for different constructions were sought. Not only the sign for zero, but also the binary number system, infinity and its operations, the ideas of metarules, algebraic transformation, recursion, hashing, mathematical logic, formal grammars, and high level language description arose first in India.

The *Śulbasūtras*

The *Śulbasūtras* belong to the *Vedāngas*, or supplementary texts of the Vedas that deal with construction of geometric altars. Their contents, written in the condensed *sūtra* style, cover geometrical propositions and problems related to rectilinear figures and their combinations and transformations, squaring the circle, as well as arithmetical and algebraic solutions to these problems. The root *śulb* means measurement, and the word *śulba* means a cord, rope, or string.

The extant *Śulbasūtras* belong to the schools of the Yajurveda. The most important *Śulba* texts are the ones by ► Baudhāyana, Āpastamba, Kātyāyana, and Mānava. They have been generally assigned to the period 800–500 BCE of which Baudhāyana's text is the oldest. Baudhāyana begins with units of linear measurement and then presents the geometry of rectilinear figures, triangles, and circles, and their transformations from one type to another using differences and combinations of areas. Approximations to the square root of 2 and to π are given next.

In the methods of constructing squares and rectangles, several examples of Pythagorean triples are provided. It is clear from the constructions that both the algebraic and the geometric aspects of what we call the Pythagorean theorem were known. Several geometric constructions in these texts are based on algebraic solutions of simultaneous equations of linear and quadratic types. It appears that geometric techniques were often used to solve algebraic problems.

Jyotisha

Recent researches have established that the altar geometry of the *Śulbas* was used to represent astronomical facts related to the knowledge of the lunar and the solar years. The solution to these problems involved solution to indeterminate linear equations. Lagadha's *Vedānga Jyotisha* (1300 BCE), a book on the motions of the sun and the moon, presupposes knowledge of such equations.

Pānini's Grammar

Pānini's *Ashtādhyāyī*, "The Eight Chapters" (fifth century BCE), provides 4,000 rules that describe the Sanskrit of his day completely. The great variety of linguistic ideas used in the text mirrors the complexity of cognitive relationships that is the secret of its power and success. It is remarkable that Pānini set out to describe the entire grammar in terms of a finite number of rules. Scholars have shown that the grammar of Pānini represents a universal grammatical and computing system.

The *Ashtādhyāyī* ostensibly deals with the Sanskrit language. However, it presents the framework for a universal grammar that can apply to any language. Two important early commentaries on this grammar are by Kātyāyana and Patanjali. Bhartrihari examined its philosophical basis in an important work in the fifth century AD.

Pānini's grammar begins with metarules, or rules about rules using a special technical language, or metalanguage. Several sections follow on how to generate words and sentences starting from roots, as well as rules on transformation of structure. The last part of the grammar is a one-directional string of rules, where a given rule in the sequence ignores all rules that follow. Pānini also uses recursion by allowing elements of earlier rules to recur in later rules. This anticipates in form and spirit by more than 2,500 years the idea of a computer program.

In Pānini's system, a finite set of rules is enough to generate an infinity of sentences. The algebraic structure of Pānini's rules was not appreciated in the West until about 50 years ago when Noam Chomsky proposed a similar generative structure. Before this, in the nineteenth century, Pānini's analysis of roots and suffixes and his recognition of ablaut led to the founding of the subjects of comparative and historical linguistics.

Pānini took the idea of action as defined by the verb and developed a comprehensive theory by providing a context for action in terms of its relations to agents and situations. This theory is called the *kāraka* theory. These *kārakas* are:

1. That which is fixed when departure takes place
2. The recipient of the object
3. The instrument, or the main cause of the effect
4. The basis, or location
5. What the agent seeks to attain, deed, object
6. The agent

These *kārakas* do not always correspond to the nature of action; therefore, the *kāraka* theory is only a via *media* between grammar and reality. It is general enough to subsume a large number of cases, and where not directly applicable, the essence of the action/transaction can still be cast in the *kāraka* mold. To do this, Pānini requires that the intent of the speaker be considered. Rather than a structure based on conventions regarding how to string together words, Pānini's system is based on meaning.

Chhandahśāstra and *Nātya Śāstra*

The *Chhandahśāstra* of Pingala (400 BCE according to tradition) describes the binary number system. The idea of mathematical zero is also implicit in some of Pānini's rules. The *Nātya Śāstra* presents important results on permutations and combinations. Further results are to be found in later books on musicology such as the *Brihaddeśi* and the *Sangīta-Ratnākara*.

The Siddhāntic Age

► Āryabhaṭa (born 476) presented the first general solution to the linear indeterminate equation using the method of *kuttaka*. ► Brahmagupta (seventh century) solved the quadratic indeterminate equation $Nx^2 + 1 = y^2$. Brahmagupta's expressions for the diagonals of a cyclid quadrilateral are considered most extraordinary.

Virahānka (eight century) gave an explicit rule for what we call the Fibonacci sequence. Vīrasena (ninth century) knew the logarithm to base 2 and its properties. Jayadeva of the same period developed the *chakravāla* (cyclic) method which, according to Hankel, is the "finest thing achieved in the theory of numbers before Lagrange (eighteenth century)." Bhāskara (born 1114) made further advances to trigonometry and analysis.

Navya Nyāya

Navya Nyāya (New Logic) began in Mithila under the leadership of Gangeśa Upādhyāya (twelfth century). The scholars of this school developed an elaborate technical vocabulary and logical apparatus that came to be used by philosophers and writers on law, poetics, aesthetics, and ritualistic liturgy. In their technique of analyzing knowledge, judgmental knowledge was analyzed into three kinds of epistemological entities in their interrelations: "qualifiers"; "qualificandum," or that which must be qualified; and "relatedness." Further abstract entities used were qualifierness, qualificandumness, and relatedness. The knowledge expressed by the judgment "This is a blue pot" may then be analyzed into the following form:

> The knowledge that has a qualificandumness in what is denoted by 'this' is conditioned by a qualifierness in blue and also conditioned by another qualifierness in potness.

At its zenith during the time of Raghunātha (1475–1550), this school developed a methodology for a precise semantic analysis of language. Its formulations are equivalent to mathematical logic.

Kerala Mathematicians

The Kerala school of mathematics flourished during 1200–1600 in South India. One of its great figures, Mādhava (ca. 1340–1425), also provided methods to estimate the motions of the planets. He gave power series expansions for trigonometric functions, and for π correct to 11 decimal places.

A very prolific scholar who wrote several books on astronomy, Nīlakaṇṭha (ca. 1444–1545), found the correct formulation for the equation of the center of the planets and his model is nearly a true heliocentric model of the solar system. In it, the planets go in eccentric orbits around the mean Sun, which in turn goes around the Earth. He also improved upon the power series techniques of Mādhava.

These mathematicians made truly fundamental advances in analysis including infinite series and calculus. Almeida and his collaborators have suggested that Jesuit missionaries brought this work to Europe and it may have provided the spark for the European mathematical revolution.

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Conics

Jan P. Hogendijk

The theory of conic sections was discovered in Greece around 350 BCE. The most comprehensive ancient treatise on the subject was the *Conics* of Apollonius of Perga (fl. ca. 200 BCE). This treatise consisted of eight Books, of which only the first four have come down to us in Greek. Apollonius considered an arbitrary cone with a circular base, whose apex is an arbitrary point not in the plane of the base. He obtained the conic sections as intersections of this cone by a plane not through the apex. Apollonius distinguished three types of conic sections: the ellipse, the parabola, and the hyperbola.

The story of the translation of the *Conics* into Arabic is interesting, because it shows the difficulty of translating a technical mathematical text. The first Arabic geometers with an interest in the *Conics* were the three ▶ Banū Mūsā ("sons of Mūsā," fl. ca. AD 830). At first they possessed only one poor Greek manuscript, containing the first seven Books, and they were unable to understand the very technical contents. Then one of the brothers, al-Ḥasan, decided to develop the theory of the ellipse as the intersection of a cylinder and a plane. He believed that the cylinder was easier than the cone, and he hoped that the theory might be more accessible this way. Al-Ḥasan wrote a book on his discoveries, entitled *Al-shakl al-mudawwar al-mustaṭīl* (The Rounded Elongated Figure). This work is lost.

After the death of al-Ḥasan, his brother Aḥmad obtained a second manuscript of the first four Books of the *Conics* in Syria, together with the commentary of Eutocius of Ascalon (ca. AD 500). This manuscript was much better than the other one, and with the help of the book of his deceased brother, Aḥmad was able to make sense of the contents of the Greek text. He then inserted cross-references in the Greek in order to make the text more comprehensible. Now that he understood the first four Books, Aḥmad was able to make sense of Books V–VII on the basis of the other manuscript. He then had the Books translated: Books I–IV by Hilāl al-Ḥimṣī, Books V–VII by ▶ Thābit ibn Qurra. Aḥmad supervised and corrected the translation. Thus Aḥmad ibn Mūsā and Thābit rescued one of the most interesting mathematical works of antiquity, namely Books V–VII of the *Conics*. Book VIII of the *Conics* seems to have been lost altogether. It was reconstructed around 1000 by Ibn al-Haytham, and around 1700 by Edmund Halley.

By the ninth century, geometers in the Arabic tradition had already written treatises on conic sections. Thābit ibn Qurra authored a work on plane sections of a cylinder, which is extant. A popular subject was the determination of the surface areas of segments of conic sections and the volumes of solids obtained by revolving a segment of a conic section about one line (such as the axis or the base). The Arabic geometers knew that Archimedes had solved this problem for the parabola, but they did not know his method of solution. The treatises on this subject by Thābit ibn Qurra, and by the tenth-century mathematicians al-Qūhi and Ibn al-Haytham, are among the highlights of Arabic mathematics.

The Arabic geometers applied conic sections in the solution of a group of problems (trisection of the angle, construction of two mean proportionals, construction of the regular heptagon, etc.) which could not be solved by means of ruler and compass. In the tenth century AD, most geometers in Iraq and Iran considered straight lines, circles, and conic sections the only legitimate means of construction in geometry. The reason was that these objects belonged to fixed (immovable) geometry (*al-handasa al-thābita*), whereas all other curves and instruments were believed to be created by motions and instruments, which did not belong to mathematics but to mechanics.

Conics were also used in the solution of the "Problem of Alhazen" (named after al-Ḥasan ibn

al-Haytham, mentioned above). In this problem, the positions of the eye, the object, and a convex or concave spherical, cylindrical, or conical mirror are given. One asks for the points of the mirror at which the object is reflected to the eye. Ibn al-Haytham constructed these points of reflection, and he showed that the object is reflected at no more than four points on the mirror. His solution is very intelligent but also extremely complicated, and several seventeenth-century European mathematicians complained about its difficulty. Earlier, the solution had been simplified by al-Muʾtaman ibn Hūd, the king of Zaragoza (d. 1085), but this simplification was unknown in Christian Europe.

In the tenth century, al-ʿAlāʾ ▶ ibn Sahl studied reflection in parabolic lenses (which had been studied before) and refraction in hyperbolic lenses (this topic was new). He showed that rays parallel to the axis are refracted to one of the foci of the hyperbola. The reasoning implies knowledge of what we now call Snell's law of refraction, but it is unclear how al-ʿAlā discovered this law.

An important field of application of conic sections was the theory of cubic equations. A cubic equation is an equation of the form $x^3 + ax^2 + bx + c = 0$, for a, b, c given numbers. The Arabic geometers were unable to solve this equation algebraically, i.e., to say, by expressing the root x in terms of a, b, and c. However, they learned to solve it geometrically. The history of the theory is connected with a certain division of a line segment mentioned by Archimedes in Proposition 4 of Book II of *On the Sphere and Cylinder*. Archimedes used the divided line segment but he did not show how it could be divided. In the ninth century, ▶ al-Māhānī showed that the division of the line segment, which Archimedes uses, depends on a cubic equation of the form $x^3 + c = ax^2$ (a and c are positive). However, he was unable to solve this equation. Abū Jaʿfar al-Khāzin (tenth century) knew the work of al-Māhānī and also a commentary by Eutocius of Ascalon (ca. AD 500), who shows how the line segment can be divided by means of conic sections. Apparently, Abū Jaʿfar realized that one could use Eutocius' construction using conic sections to find the root x of the equation $x^3 + c = ax^2$ to which al-Māhānī had reduced the problem. Soon other Arabic geometers discovered that conic sections could also be used to solve other "types" of cubic equations. (Because they only worked with positive coefficients, they distinguished different types of equations, e.g., $x^3 + c = ax^2$ is of a type different from $x^3 + ax^2 = c$, etc.) In the eleventh century, ʿUmar al-Khayyām gave in his *Algebra* a geometric solution (by means of conic sections) of all types of cubic equations. His theory was considerably improved by ▶ Sharaf al-Dīn al-Ṭūsī around 1200.

The Arabic mathematicians developed an instrument, the perfect compass, with which conic sections could be drawn, but this does not seem to have been much used and no examples have survived. Ibn al-Haytham used conic sections for mosaic constructions.

See Also

- ▶ al-Māhānī
- ▶ Al-Muʾtaman ibn Hūd
- ▶ Al-Qūhī (or Al-Kūhī)
- ▶ Banū Mūsā
- ▶ Ibn Al-Haytham (Alhazen)
- ▶ Ibn Sahl
- ▶ Umar al-Khayyām
- ▶ Sharaf al-Dīn al-Ṭūsī
- ▶ Thābit ibn Qurra

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Consciousness in Ancient India

Subhash Kak

The Vedic texts from ancient India (approx. 3000–1000 BCE) claim to be *ātmavidyā*, "science of self" or "consciousness science." The most ancient of these is the cryptic *ṛgveda*. But prose commentaries, called the *Brāhmanas* and the *Upanishads* that appeared in the centuries following the *Vedas*, provide a framework to decode its narrative, establishing its central concern with consciousness.

Until recently, the question of consciousness was considered to lie outside of the scope of science and, consequently, the Indian texts on the subject were not properly examined. Scientific attitudes toward consciousness have changed due to the recent advances in neuroscience and because modern physics and computer science must confront the question of the observer.

In the Vedic view, reality is unitary at the deepest level since otherwise there would be chaos. This reality is called Brahman (neuter gender). Brahman engenders and, paradoxically, transcends the mind/matter split. It is identical to consciousness at the cosmic scale and it informs individual minds. Turning focus to the very nature of the mind provides insight about consciousness.

Limitations of Language

Since language is linear, whereas the unfolding of the universe takes place in a multitude of dimensions, language is limited in its ability to describe reality. Because of this limitation, reality can only be experienced and never described fully. All descriptions of the universe lead to logical paradox, and Brahman is the category transcending all oppositions. Vedic ritual is a symbolic retelling of this worldview.

Knowledge is classified in two ways: the higher or unified, and the lower or dual. The higher knowledge concerns the perceiving subject (consciousness), whereas the lower knowledge concerns objects. The higher knowledge can be arrived at only through intuition and meditation on the paradoxes of the outer world. The lower knowledge is analytical and it represents standard sciences (*śāstra*) with its many branches. In addition, *darśana* represents philosophy where the problem of self is taken together with some aspect of outer reality. There is a complementarity between the higher and the lower, each being necessary to define the other. This complementarity mirrors the one between mind and body.

Recursive Reality and Mind

The Vedic texts present a tripartite and recursive view of the world. The universe, viewed as three regions of earth, space, and sky, is mirrored in the physical body, the breath (*prāna*), and mind. This connection is a consequence of a binding (*bandhu*) between various inner and outer phenomena.

The universe is understood to be a living organism and therefore subject to cycles of life and death. The universe evolves according to cosmic law. Since it cannot arise out of nothing, the universe must be infinitely old. Since it must evolve, there are cycles of chaos and order or creation and destruction.

In the Vedic discourse, the cognitive centers are called the *devas*, deities or gods, or luminous loci. Thus the *Atharvaveda* calls the human body the city of the *devas*. Each *deva* reflects primordial consciousness and one can access the mystery of consciousness through any of these.

Mind in Indian Philosophy (*Darśana*)

The six systems of Indian philosophy are paired together in three complementary groups: logic (*Nyāya*) and physics (*Vaiśeshika*); cosmology (*Sāmkhya*) and psychology (*Yoga*); and language (*Mimāmsā*) and reality (*Vedānta*). Although these philosophical schools were formalized in

the post-Vedic age, we find the basis of these ideas in the Vedic texts. In each of these, the question of the experiencing self is included.

The objective of the Nyāya is *anvīkshiki*, or critical inquiry. Its beginnings go into the Vedic period, but its first systematic elucidation is given by Gautama in his *Nyāya Sūtra* (third century BCE). The text begins with the nature of doubt and the means of proof, considering the nature of self, body, senses and their objects, cognition, and mind. The Nyāya is also called *pramāna śā stra* or the science of correct knowledge. Knowing is based on four conditions:

1. The subject or the *pramātri*
2. The object or the *prameya* to which the process of cognition is directed
3. The cognition or the *pramiti*
4. The nature of knowledge or the *pramāna*

Gautama mentions that four factors are involved in direct perception: the senses (*indriyas*), their objects (*artha*), the contact of the senses and the objects (*sannikarsha*), and the cognition produced by this contact (*jnāna*). The five sense organs – eye, ear, nose, tongue, and skin – have the five elements – light, ether, earth, water, and air – as their field, with corresponding qualities of color, sound, smell, taste, and touch.

Manas or mind mediates between the self and the senses. When the *manas* is in contact with one sense organ, it cannot be so with another. It is therefore said to be atomic in dimension. It is because of the nature of the mind that our experiences are essentially linear, although the quick succession of impressions may give the appearance of simultaneity.

Objects have qualities which do not have their own existence. The color and class associated with an object are secondary to the substance. According to Gautama, direct perception is inexpressible. Things are not perceived as bearing a name. The conception of an object on hearing a name is not direct perception but verbal cognition.

According to the atomic doctrine of Vaiśeshika ascribed to Kanāda, there are nine classes of substances: ether, space, and time that are continuous; four elementary substances (or particles) called earth, air, water, and fire that are atomic; and two kinds of mind, one omnipresent and another which is the individual. The conscious subject is separate from the material reality but he is, nevertheless, able to direct its evolution.

The Sāmkhya and the Yoga systems take the mind as consisting of five components: *manas*, *ahamkāra*, *chitta*, *buddhi*, and ātman. *Manas* is the lower mind which collects sense impressions. *Ahamkāra* is the sense of I-ness that associates some perceptions to a subjective and personal experience. Once sensory impressions have been related to I-ness by *ahamkāra*, their evaluation and resulting decisions are arrived at by *buddhi*, the intellect. *Chitta* is the memory bank of the mind. These memories constitute the foundation on which the rest of the mind operates. But *chitta* is not merely a passive instrument. The organization of the new impressions throws up instinctual or primitive urges which create different emotional states. This mental complex surrounds the innermost aspect of consciousness, which is *ātman*, the self.

Yoga psychology of Patanjali is a very sophisticated description of the nature of the human mind and its capacity. It makes a distinction between memory, states of awareness, and the fundamental entity of consciousness. It puts the analytical searchlight on mind processes with clarity and originality.

Mīmāmsā and Vedānta consider the analysis of language and reality, respectively. Mīmāmsā ideas became a part of the grammatical tradition and Vedānta became a vehicle to consider consciousness in the most abstract sense.

Parallels with Cognitive Science

There are intriguing parallels between the insights of the early Vedic theory of consciousness and those of quantum mechanics and neuroscience. To express Vedic ideas in modern terms, one might say that individual minds emerge out of the reflection that the brain

provides to the underlying illuminating consciousness. Therefore, senses of awareness, such as vision and hearing, may be separated from the person who obtains this awareness.

The human brain represents the clearest structure to focus the self, which is why humans are able to perform in ways that other animals cannot. Self-awareness is an emergent phenomenon which is grounded on the self and the associations stored in the brain.

From a modern scientific viewpoint, living systems are dynamic structures, defined by their interaction with their environment. Living systems may also be defined recursively in terms of living subsystems. Thus, for ants, one may consider their society, an ant colony, as a living superorganism; in turn, the ant's subsystems are also living. Such a recursive definition appears basic to all life. Machines, on the other hand, are based on networking of elements that create a well-defined computing procedure, but they lack a recursive self-definition.

The Vedic system, which was an earlier attempt to unify knowledge, was confronted by paradoxes similar to that of contemporary science. It is noteworthy that Schrödinger, the co-creator of quantum theory, admitted to having been inspired by the Vedic texts. According to his biographer Walter Moore, there is a clear continuity between Schrödinger's understanding of Vedānta and his research:

> The unity and continuity of Vedanta are reflected in the unity and continuity of wave mechanics. In 1925, the world view of physics was a model of a great machine composed of separable interacting material particles. During the next few years, Schrödinger and Heisenberg and their followers created a universe based on superimposed inseparable waves of probability amplitudes. This new view would be entirely consistent with the Vedantic concept of All in One (Moore, 1989, p. 173).

The similarity between the Vedic system and quantum mechanics and the fact that quantum mechanical models of consciousness are being attempted leads us to ask how far the Vedic thinkers took their classificatory models of consciousness. We find both hierarchical and distributed cognitive centers listed in the Vedic texts.

Further Universal Categories

If the categories of the mind arise from pattern recognition of shadow mental images, then how are these categories associated with a single "agent," and how does the mind bootstrap these shadow categories to find the nature of reality?

These questions are examined in the later Vedic tradition both within the frameworks of Vaishnavism and Shaivism. Of the latter tradition, the later Kashmir Shaivism of Vasugupta (AD 800) has in recent years received considerable attention (Shiva is the name for the absolute consciousness).

According to Sāmkhya, reality may be represented in terms of 25 categories. These categories form the substratum of the classification in Kashmir Shaivism. The Sāmkhya categories are:

1. Five elements of materiality, represented by earth, water, fire, air, and ether
2. Five subtle elements, represented by smell, taste, form, touch, and sound
3. Five organs of action, represented by reproduction, excretion, locomotion, grasping, and speech
4. Five organs of cognition, related to smell, taste, vision, touch, and hearing
5. Three internal organs, mind, ego, and intellect
6. Inherent nature (*prakriti*) and consciousness (*purusha*)

These categories define the structure of the physical world and of agents and their minds.

Kashmir Shaivism enumerates further characteristics of consciousness:

1. Sheaths or limitations of consciousness, being time (*kāla*), space (*niyati*), selectivity (*rāga*), awareness (*vidyā*), creativity (*kalā*), and self-forgetting (*māyā*)
2. Five principles of the universal experience, which are correlation in the universal experience (*sadvidyā*, *śuddhavidyā*), identification of the universal (*īśvara*), the principle of being (*sādākhya*), the principle of negation

and potentialization (*śakti*), and pure awareness by itself (*śiva*)

The first 25 categories relate to an everyday classification of reality. The next 11 categories characterize different aspects of consciousness that are to be understood in a sense different to that of mental capacities (categories 21–23). One of these mental capacities is akin to artificial intelligence, which is geared to finding patterns and deciding between hypotheses. On the other hand, categories 26–36 deal with interrelationships in space and time between these patterns and deeper levels of comprehension and awareness.

Deterministic science cannot explain free will. If consciousness is seen as emerging from the ground of the classical world, then scientific laws again remain incomplete. On the other hand, we do not know why the brain-machine has awareness whereas computers never will. Nor do we understand the mechanisms behind psychoneuroimmunology or the astonishing abilities of savants.

The Indian approaches to consciousness seem to have anticipated many difficulties of contemporary science. The classificatory systems developed in the Indian tradition define categories, such as that of universal experience, that can be seen to explain the "complementary" nature of human experience. These categories clearly assign a central role to selectivity, or context, and change. The Vedic system takes the mind to be emergent on the ground of the brain, but this emergence is contingent on the principle of consciousness.

The ancient Indian texts of consciousness were long limited to philosophical analysis alone, remaining an unexplored frontier in the history of science. Further advances in a scientific understanding of mind will lead to a better appreciation of these texts.

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Copper in Zimbabwe

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Early farming communities in central and southern Africa were aware of mineral resources. Iron and copper have been extracted and used since the beginnings of farming in the region in the first millennium AD. The use of gold in particular and tin to a limited extent developed later as economic resources for social hierarchies that began to emerge at the beginning of the second millennium AD. Dubbed the "red gold of Africa" (Herbert, 1984), copper in the Zimbabwean archaeological record contrasts with gold. Gold was mined on a large scale, primarily for export via the east coast Indian Ocean trade network, with limited local use by elite of the second millennium political hierarchy on the

Zimbabwean plateau and in the Limpopo valley. Copper on the other hand was mined for local use as items of personal adornment and as symbols of wealth and position among the socially elite.

Mining

Precolonial mine workings existed on the Central African Copper Belt (Bisson, 1976) the copper-bearing geology of Zimbabwe (Summers, 1969; Swan, 2002), in eastern Botswana (Huffman et al., 1995), and northern South Africa (Van der Merwe & Scully, 1971). Brightly colored malachite and azurite ores likely drew attention to surface outcrops of the resources. Stopes that narrowly followed reefs were tunneled into resources using iron gads hafted through wooden handles, leaving tool marks on rock surfaces. Gads were struck with hammerstones that became dimpled from repeated impact. Chunks of ore were pounded and split using hammerstones to allow selection of pieces rich in copper for transportation away from the mine site.

Debris accumulated around the mines and disused workings. In addition to waste rock and discarded hammerstones, archaeological excavations of these deposits have recovered potsherds and charcoal can be used to indicate time frames.

Manufacture, Use, and Trade

Evidence for copper smelting in Zimbabwe is limited to small quantities of slag and tuyere fragments, so little is known about the methods and types of furnace used. Cup-shaped ceramic crucibles with external surfaces glazed with slag, housed in museum collections, were presumably used in a final purification process (Friede & Steel, 1975) before pouring the molten copper into a mold.

Refined copper was fashioned into beads or into wire by wrenching it with tongs through successively smaller holes in an iron drawplate. The wire was wound in a tight spiral around a fiber core to make bangles for wrists and ankles. Copper artifacts of this type are reasonably common in the Zimbabwean archaeological record suggesting availability to all levels of society, especially in the second millennium AD.

Two types of copper X-shaped ingots found in northern Zimbabwe appear to have played several roles (Swan, 2007). The earlier of these are about 18 cm long and weigh between 350 and 1,300 g. These have been compared with ceramic molds on the Central African Copper Belt dating from the ninth to the twelfth century AD (Bisson, 1976) and with ingots deposited in elite burials dating in the thirteenth and fourteenth centuries AD, found near the Lualaba River in the Democratic Republic of the Congo (de Maret, 1995). The distribution of this ingot type extended eastward to Mozambique until the fourteenth century and southward to northern Zimbabwe. Reasonably standardized size, shape and weight suggest use as general-purpose currency (Bisson, 1975). Toward the south of Zimbabwe, molds and an ingot found at elite stone-walled settlements of the Zimbabwe state reflect a wider distribution as items of prestige or royal insignia.

Larger X-shaped ingots, around 30 cm long and weighing 3–4.5 kg, are more common than the smaller type in northwestern Zimbabwe. One mold made of soapstone demonstrates local manufacture from copper mined in the region. Found in caches and occasionally with arms broken off, these ingots could have operated as general-purpose currency and for wealth storage and were probably traded as raw material. The most informative archaeological site is Ingombe Ilede near the Zambezi River (Fagan, Phillipson, & Daniels, 1960), where ingots and other artifacts associated with wealth and metalworking were placed in human graves in the fifteenth century AD. Historical documents record their use as trade items in the sixteenth century (Garlake, 1970; Bisson, 1975).

Musuku-type ingots (Hanisch, 1974) found in southern Zimbabwe indicate connections with communities living to the south of the Limpopo River.

Social Context

The stimulus to mining and the social and economic organization of metal production and exchange of goods are poorly understood, but the use of copper from the mid-first millennium AD and increases in production prior to the introduction of imports from outside Africa support the notion that the seeds of social hierarchy were present in the region, discrediting earlier notions that trade contact was the initial stimulus to political centralization (Bisson, 1976). It has been suggested that the elite rank of society mediated in the distribution of subsistence requirements and trade items (Vogel, 1990; Swan, 2008).

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Copper Production in Mexico

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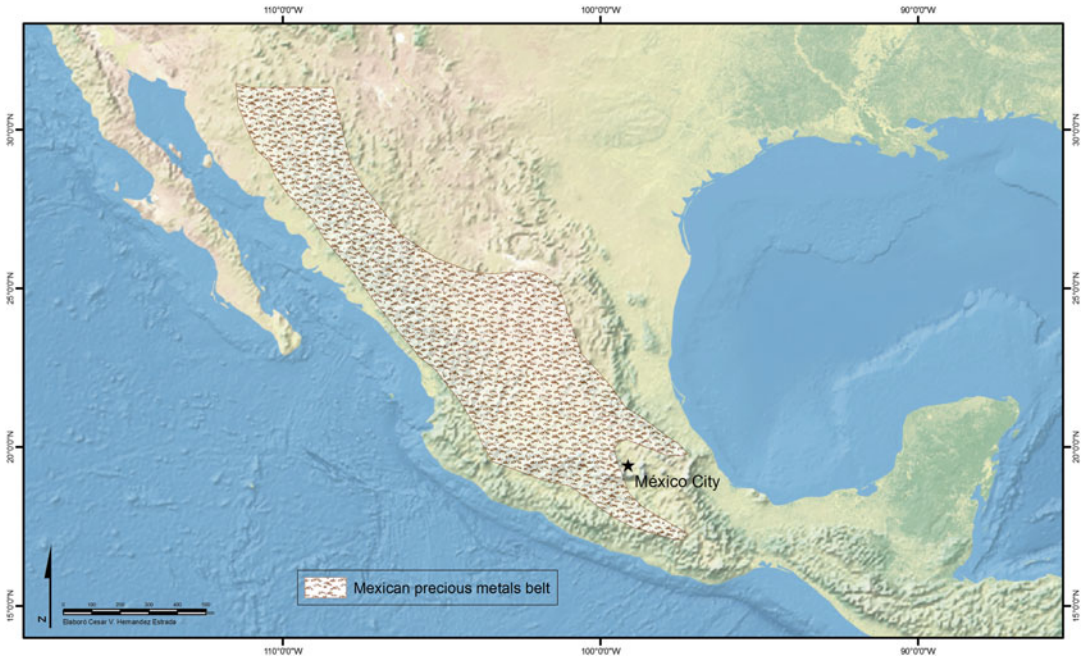
Copper is a metal more easily smelted than iron and has qualities of malleability, reasonable tensile strength, and corrosion resistance that made it commonly used in preindustrial times (Forbes, 1950) (Video 1). From the standpoint of the Middle American peoples, it was the most important metal and played a prominent role in the prehispanic metallurgy of Ancient Mexico (Hosler, 1994). Today, copper is one of the cornerstones of the Mexican economy.

Most of the Mexican territory lies within a metalliferous zone known as the precious and base metal province of Mexico (Fig. 1). The variety of metals available in this zone is relatively abundant, with copper present largely in the form of ores that have to be extracted from underground deposits. These can be divided into two groups: the easily reducible oxide and carbonate ores, and the more complex ores of the sulfide type. Copper oxides and carbonates are found mainly as cuprite, malachite, and azurite; copper sulfides include chalcopyrite, chalcocite, and bornite. Added to these is native copper,

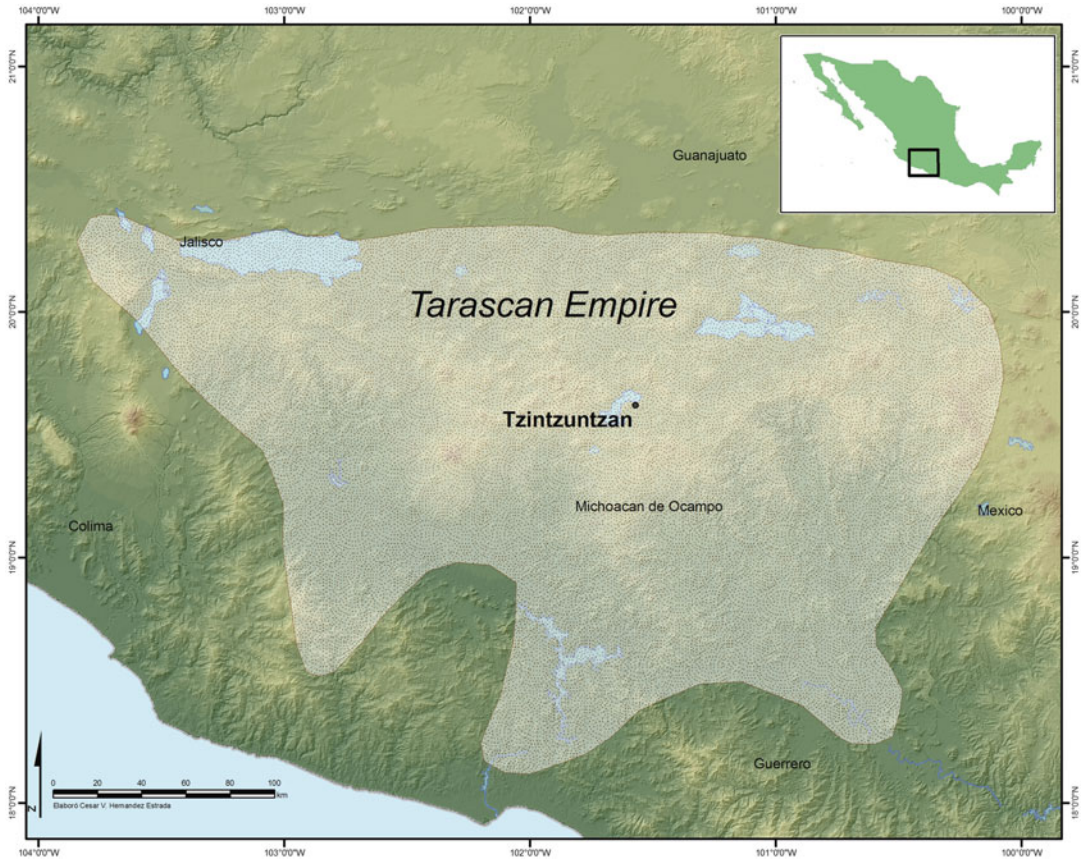
Copper Production in Mexico, Video 1 Making history: malachite and copper (3:52 min.) https://www.youtube.com/watch?v=OrBw4L490Y



Copper Production in Mexico, Fig. 1 The precious and base metal province of México (Based on data from the Mexican Geological Survey (SGM) [http://www.sgm.gob.mx])

which is found in a pure state and was readily available on the surface in some locales (Ostroumov & Corona-Chávez 2000; Ostroumov, Corona-Chávez, Díaz de León, Morales, & Cruz, 2002).

In Ancient Mexico, copper was not only the predominant metal but also the most extensively used base material. Between ca. A.D. 650 and 1200 or 1300, indigenous metalworkers from Michoacan, Jalisco, Colima, northwest Guerrero, and the southern parts of the state of Mexico, appear to have worked almost exclusively with native copper and easily smelted oxidized copper ores. But from 1300 to the Spanish conquest in 1521, they combined copper with other elements to produce a variety of alloys, including binary alloys such as copper-silver, copper-gold, copper-arsenic, and copper-tin



Copper Production in Mexico, Fig. 2 The maximum extension of the Tarascan Empire in the Late Postclassic period (Based on Pollard 1993:5)

and ternaries like copper-silver-gold, copper-silver-arsenic, copper-arsenic-antimony, and copper-arsenic-tin (Grinberg, 1996; Hosler, 1988b, 1994, 1995).

In the early sixteenth century, the Tarascan kingdom of Michoacan (Fig. 2) was the primary center for metallurgy and metalworking in the region. This technology was largely based on copper and its alloys. Prehispanic copper exploitation reached its height from A.D. 1450 to 1530 in the Tarascan domain. At the time of the Spanish conquest, the Tarascan language used the term *tiyamu charapeti haracuquaro* to refer specifically to copper miners (*tiyamu charapeti* meaning copper or "red metal").

Presumably, the use of metal goods such as axe-monies, depilatory tweezers, bells, and other ritual objects and adornments (Fig. 3) among the Tarascans and their neighbors was restricted to the central dynasty and the nobility. Although some utilitarian implements were made, most metal objects were considered to be sacred, to be used for adornment in religious ceremonies, and to enhance the social and political status of the elites (Fig. 4; Hosler, 1988a, 1994; Pollard, 1987, 1993).

Artisans from Santa Clara del Cobre, a modern Tarascan municipality in Michoacan, have maintained the traditional techniques for working copper to this day. Essentially the method employed by these contemporary craftsmen is based on the use of the *cendrada*, a hole in the ground lined with oak ashes which functions as a mold to produce a *tejo*, a disklike copper ingot, which is then hammered into finished shapes (Videos 2a and 2b). Information provided by written sources, along with the factual presence

Copper Production in Mexico, Fig. 3 Experimental replicas of Tarascan copper artifacts, produced by B. Maldonado (2006)

Copper Production in Mexico, Fig. 4 Tarascan priest wearing a metal tweezer. From Jerónimo de Alcalá, Relación de Michoacán, Moisés Franco Mendoza (estudios y coord. de la edición), Zamora, Gobierno del Estado de Michoacán-El Colegio de Michoacán, 2000, lám. II [primera ed. ca. 1539–1541]

of smelting waste products (i.e., slag) on the surface of archaeological areas near Santa Clara, indicate that the ongoing production of copper has its roots in prehispanic traditions (Horcasitas de Barros, 1981; Maldonado, 2006; Maldonado & Rehren, 2009).

After the Spanish conquest, the principal source of copper in New Spain continued to be the Province on Michoacan, with the main center of copper mining at Real the Inguaran. When Spaniards took over the local copper industry in 1533, natives were employed as both miners and

Copper Production in Mexico, Video 2a Santa Clara del Cobre: Artesano del Cobre – Parte 1 (7:30 min) https://www.youtube.com/watch?v=G6xZgO8xiCY

Copper Production in Mexico, Video 2b Santa Clara del Cobre: Artesano del Cobre – Parte 2 (8:39 min.) https://www.youtube.com/watch?v=9HcZP9Y2FO8

smelters and for decades continued to use the metallurgical techniques that they knew. According to testimony given in 1533 by Indians who worked in the mines, copper production was much lower than it had been before the conquest (Bargalló, 1955, pp. 213, 295; Barrett, 1987, pp. 14). The low level of production was undoubtedly associated with the continuing decline in indigenous population that followed the Spanish conquest.

The history of commercial mining in Mexico dates back to the Colonial Period. Because of its use in many critical sectors of the economy, copper was a significant resource in New Spain. In a society where iron goods were scarce, copper (unalloyed or mixed with tin or zinc to produce bronze or brass) was indispensable. It was the most widely employed utilitarian metal in Spanish Colonial times. Its importance is manifest in the many ways it was used, from coinage and

armaments to innumerable articles of industrial, domestic, and artistic use. In its nonmetallic form, it was used to process silver ore. In the eyes of the crown, the use of copper for making silver and gold coins and armaments commanded the highest priority followed by its use for making utensils and equipment needed in the manufacture of sugar (Barrett, 1987).

During the next 300 years of Spanish rule, different minerals were extracted from the ground, including copper, coal, lead, and iron. Copper was extracted mainly from the Inguaran mines and the surrounding areas, which remain today among the major mineral deposits in Mexico. Because of its strategic importance, the Spanish crown maintained a monopoly on this mineral resource through the early nineteenth century.

Over the last 100 years, porphyry or high-grade underground mines and large-scale open-pit mines have helped make Mexico one of the larger copper producers in the world, providing approximately 8 % of annual world copper production (Cardenas-Vargas, 1993), mostly from two mines, Cananea and La Caridad. The porphyry copper deposits of Mexico range from the economically insignificant and/or unexplored to the world-class deposits exploited in the Cananea and Nacozari Districts of Sonora (Barton, Staude, Zürcher, & Megaw, 1995). In 2011, 94 % of all copper production took place in the following states: Sonora (80 %), Zacatecas (9 %), and San Luis Potosi (5 %) (Perez, 2011).

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Cosmetic Surgery in Ancient India

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Cosmetic operations form a special corner in medicine – much in demand and yet often much maligned for being unnecessary or frivolous. This assumes a clear-cut division between a narcissistic desire for an improved appearance, the correction of a disfigurement or injury that altars appearance in an alarming way without altering physiologic function, and the real disability and danger caused by a disease. Whatever the clarity of the division, the demand persists and also reaches back into antiquity. The undisputed father of the field of cosmetic surgery is Suśruta, a surgeon, educator, and compiler who lived probably around the sixth to eighth century BCE, though his possible dates vary greatly from 1200 AD to well before 1000 BCE. No original texts of his great work, the *Saṃhitā*, exist today. It has been edited and revised throughout its history, the most significant contributions made by Nāgārjuna, who lived most probably in the second century BCE.

The *Suśrutasaṃhitā* is a remarkable work in its originality and scope. Though Suśruta is remembered as a surgeon, and division of medical specialists was practiced at his time (into surgeons, physicians, poison curers, and demon doctors), the Saṃhitā covers a very broad range of medicine as well as surgery, from discussions of the origins of disease, to the treatment of postpartum depression, to the causes of obesity. Remarkable detail is presented on the preoperative preparation of patients and the postoperative care of their wounds. Methods of intraoperative anesthesia and postoperative pain relief are discussed. Over 760 medications are described, 1,120 medical conditions including 76 of the eye alone, more than 125 surgical instruments, and 300 surgical procedures in over 1,000 pages of text and 186 chapters. A broad scope of surgery is also presented, including intestinal repair (with black ants) and Cesarean section. Methods of medical education are discussed including cadaveric and animal dissection for the purpose of learning surgical anatomy; only the bodies of children less than 2 years old could be dissected. Physiology, medical botany, hygiene, and public health are discussed, and Suśruta embraced the Ayurvedic (the science of life) approach to medical care.

Yet it is as a cosmetic surgeon that Suśruta is remembered, at least outside of India. And largely for a single operation and even more specifically for a single aspect of the technique for that operation: that of flap formation for the reconstruction of a severed nose. Here is a selection from the 1907 complete (first) English translation of the *Suśrutasaṃhitā* by K. K. Bhishagratna:

Rhinoplastic Operations: Now, I shall deal with the process of affixing an artificial nose. First, the leaf of a creeper, long and broad enough to fully cover the whole of the severed or clipped off part, should be gathered; and a patch of living flesh, equal in dimension to the preceding leaf, should be sliced off (from down upward) from the region of the cheek and, after scarifying it with a knife, swiftly adhered (sutured) to the severed (base of the) nose. The cool-headed physician should steadily tie it up with a bandage decent to look at and perfectly suited to the end for which it has been employed (Sadhu Bandha). The physician should make sure that the adhesion of the

severed parts has been fully effected and to insert two small pipes into the nostrils to facilitate respiration and to prevent the adhesioned flesh from hanging down. After that, the adhesioned part should be dusted with the powders of Pattanga, Yastimadhuka, and Rasanjana pulverized together, and the nose should be enveloped in Karpasa cotton and several times sprinkled over with the refined oil of pure sesamum. Clarified butter should be given to the patient for drink, and he should be anointed with oil and treated with purgatives after the complete digestion of the meals he has taken, as advised. Adhesion should be deemed complete after the incidental ulcer had been perfectly healed up, while the nose should be again scarified and bandaged in the case of semi- or partial adhesion. The adhesioned nose should be tried to be elongated (or trimmed) where it would fall short of its natural and previous length, or it should be surgically restored to its natural size in the case of the abnormal growth or its newly formed flesh. The mode of bringing about the adhesion of severed lips is identical with what has been described in connection with a severed nose with the exception of the insertion of the pipes. The physician, who is conversant with these matters, can be alone entrusted with the medical treatment of a King.

The innovation that made Suśruta's reputation is the skin flap to make a nose. It involved cutting three sides of a rectangle on the cheek, elevating the skin, while maintaining a blood and nerve supply from the fourth side of the rectangle, thus assuring the viability of the skin flap, which could then be slid over and formed into a new nose. Once healing was complete (and a new blood supply formed through the suture line), the fourth side of the rectangle may have been (Suśruta does not actually say he did it) divided and the donor site freed from the new nose. This is a technique used all over the body to replace skin defects today. Later editors changed the donor site to the forehead, but otherwise the technique remained largely unchanged for the next 2,000 years. Nasal reconstruction was an important part of medical practice in ancient India because nasal injury was common, sometimes through disease, but more often due to amputation, a form of punishment for many offenses, including adultery.

Yet in one manner of speaking, this is not a frivolous cosmetic operation but a reconstructive one, replacing a severed or damaged part. The Oxford English Dictionary defines "cosmetic" as "of surgery: improving or modifying the appearance. Of prosthetic devices (like grafted noses): recreating or imitating the normal appearance." In that regard the nasal, ear lobe, lip, and eyelid reconstructions described by Suśruta are certainly cosmetic.

The technique of rhinoplasty is quite briefly described with much less detail than a surgical trainee would want today before tackling this operation for the first time. Much is made today about length/width ratios of the flap or flap thickness to assure viability of the mobilized skin. Too narrow or too thin a flap would not have enough blood flow to the mobilized tip to remain viable. The graft would then die and sluff off leaving the unrepaired defect. The width and depth of stitches, the distance from the flap to the recipient site, the degree of rotation, and the time before safe detachment are all left for one to guess in the *Saṃhitā*. Much more space is devoted to the problem of severed (or bivalved) ear lobes, caused by downward pressure and erosion of earrings worn in pierced ears. Suśruta describes skin flaps again (mobilized from the nearby neck) or debridement and primary closure of the lobe if the amount of tissue was sufficient. Reconstructive procedures are also described for repair of defects, sometimes caused by surgical excision of tumors or ulcers of the eyelid and, as stated above, the lip.

See Also

► Suśruta

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Cosmologies of India

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From the viewpoint of modern astrophysics, cosmology is the study of the history, structure, and dynamics of the universe. Many of the traditional cosmological concepts of Indian culture have general counterparts in astrophysical cosmology. For example, the parallelism of the macrocosm and microcosm is an important concept for both approaches; our terrestrial physics is mirrored in the stars, galaxies, and distant quasars. Gravity and other long-range forces thread the entire universe. The geometry of Indian temples, cities, and pilgrimage landscapes often replicates the larger cosmos.

Modern physical science relies heavily on quantitative measurement, and according to the architectural traditions of India, the structure of a home, temple, and city is based upon a shared religious symbolism, which involves the bringing of cosmic order out of primordial chaos partly through the act of measurement (Malville, 1992; Zimmer, 1946). Measurement as *cosmogenesis* is asserted in many texts of Indian philosophy and mythology. Purusha, the architect of the universe, "bears the measuring rod, knows division, and thinks himself composed of parts" (Vāyu Purāṇa 4: 30–1: Kramrisch, 1946, p. 131). The universe was created as Purusha was divided into parts, many of which are the measured and ordered features of our current world such as verses, chants, social orders, time, and temples, and cities.

The universe is understood to have spread outward from a primordial center into the four cardinal directions forming a square (Kramrisch, 1946, Malville, 1991; Vatsyayan, 1983). The geometric structure of the universe, as described in the sixth century AD *Bṛhat Samhitā*, was represented by the *vāstu-maṇḍala*, usually consisting of 64 or 81 squares or *padas*, which was also the fundamental plan for houses, palaces, and cities. The *Bṛhat Samhitā* was primarily a treatise on astrology and astronomy, which provided instructions for determining auspicious dates for laying out the foundation *maṇḍala* of a building or city as well as instructions for its precise orientation to the cardinal directions using shadow casting by gnomons. Major features of the *vāstu-maṇḍala* are (1) true cardinality, i.e., parallelism to the fundamental directions in the celestial realm; (2) a center, out of which creation has emerged; (3) mathematical division of interior space into squares or *padas*; (4) the organization of space according to socioreligious rules, assigning specific *padas* to gods, kings, and social classes; and (5) a boundary that represents the barrier between internal order and external chaos.

As organized by the *vāstu-maṇḍala*, the religiously planned city was meant to be a geometrically exact copy of the macrocosm with its pantheon of gods. The symbolism of the city and temple included the point source of creation, the *garbha gṛha* (womb chamber) of the temple, and the cosmic tree separating heaven and earth, the *axis mundi*, and the surrounding squares were assigned to 44 Vedic gods, of whom eight were the all-important protector guardians of the cardinal points. The royal palace was to be constructed on one-ninth the total town area to the north of the center. A few of India's ancient cities have achieved the ideal of the *vāstu-maṇḍala* in their design, such as the excavated sites of Sisupalgarh near Bhubaneswar and

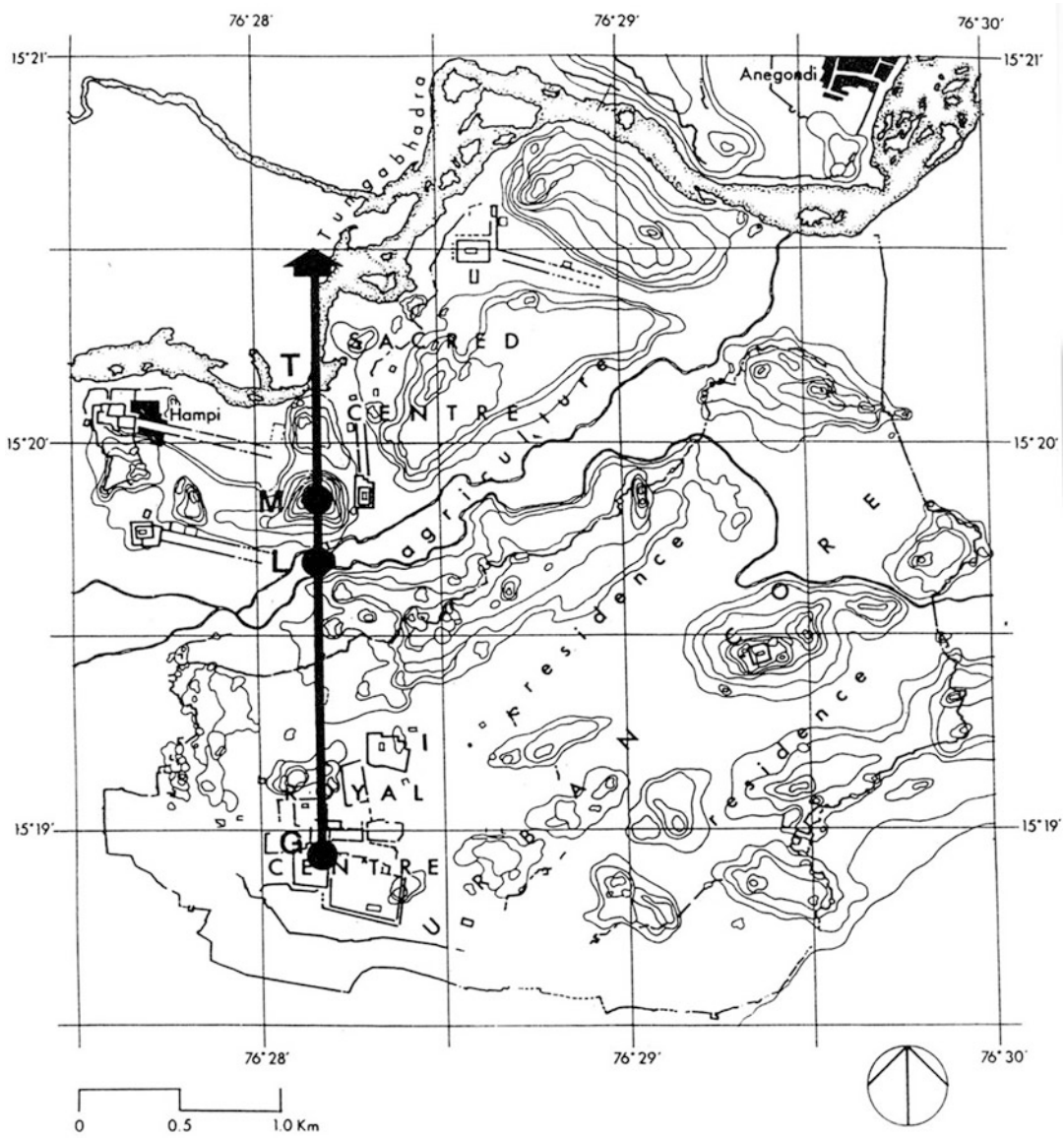
Cosmologies of India, Fig. 1 Matanga Hill as viewed from the North in the Tungabhadra River

Vaishali in North Bihar (Chakrabarti, 1997; Joshi, 2000; Krishna, 2000). Often the ideal *vāstu-maṇḍala* was compromised by local topography, as, for instance, the construction of the city on the irregular banks of a river such as Pataliputra (modern Patna) on the Gaṅgā and Ujjain on the Sipra (Krishna, 2000). Furthermore, prominent geographic features often created symbolic forces that drew the orientation of structures toward them and away from cardinality.

In the case of the great city of Vijayanagara, natural features of its dramatic landscape such as hills, caves, and river played major roles in its organization (Fritz, 1985; Fritz & Michell, 1991). With a population which may have reached 500,000 just before its destruction in 1565 AD, Vijayanagara was the greatest imperial city of medieval India, controlling the lower third of the subcontinent (Fritz, 1985). The earliest historical reference to the area is 689–690 CE, when the most important deity was the river goddess, Pampa. Her cult and that of her father, Matanga, reveal the ancient importance and sacredness of the local river and its adjacent hill. Pampa-tirtha developed into the preeminent ritual center of the region. The prominent hill named after Matanga became a place for protection from enemies. The combination of Matanga Hill, the local cosmic mountain, containing caves deep in its interior, and the Tungabhadra River resulted in a powerful shrine. According to the founding myth of the city, Vijayanagara was placed adjacent to Pampa-tirtha and Matanga Hill to benefit from the "spiritual magnetism" of a major pilgrimage center (Fig. 1).

The dominant north–south axis of the city passes across the summit of Matanga Hill. The axis passes through the Royal Center and precisely divides the domains of king and queen (Fig. 2).

On the western side of the axis lie the palaces of the queen and on the east lie the king's 100-column audience hall and the great truncated pyramid from which the king would review the parades of subject people coming to express obeisance and pay tribute (Fritz, 1985; Fritz & Malville, 1993; Malville, 2001; Malville & Fritz, 1993a). The significance of this axis and symmetries around it are laid out in the Shilpashastras such as the Manasara and



Cosmologies of India, Fig. 2 Axis of Vijayanagara

Mayamata (Fritz, 1989; Krishna, 2000). The design of the Royal Center appears to have been influenced by the cult of Rama, the hero of the Ramayana, such that the city was designed to establish and display "a homology of the king and the divine hero-king Rama" (Pollock, 1993, p. 268). The complete story of the Ramayana is contained in three circuits of carvings within the state chapel, the Ramachandra temple. That temple is rotated away from cardinality such that its minor axis is orientated to Matanga Hill, which is framed in its northern gateway, further evidence of the power of the sacred mountain. Rama's wife and queen, Sita, often identified as the ideal queen, was viewed as a vital counterpart of the king, equally necessary for the success of the kingdom. The north–south line that divides the Royal Center appears to be an architectural statement, impressive for the precision with which it was established, of the balanced structure of the

ideal medieval Hindu kingdom. Matanga Hill lies 0.8 min of arc from true north as seen from the center of the major ceremonial gateway in the Royal Center. The Indian techniques for determining true north using shadow casting by a gnomon had been perfected for centuries, culminating in the work of Sripati in the eleventh century (Yano, 1986). It appears that the architects and astronomers of Vijayanagara, just 50 years before the dawn of telescopic astronomy, were able to obtain accuracies, which were the highest achievable with the unaided human eye. If one stands at night inside the ceremonial gateway facing Matanga Hill, one can observe that the pivot of the heavens lies immediately above it. The visual conjunction of celestial pole and sacred mountain could not be more clearly presented. Beyond Matanga Hill, the north–south axis crosses Chakra-tirtha just at the place where the Tungabhadra River turns northward, in a manner similar to that of the Ganga at Varanasi. Partly for that reason, the Tungabhadra River is known as the "Ganga of the South" (Verghese, 2002). The remains of a substantial dam are found at the southern base of Matanga Hill. The dam would have impounded a lake, which was fed by a ditch from the Tungabhadra River. The lake may have been a representation of the Ocean of Milk, which lies at the foot of Mt. Meru, one of the great symbols of fertility and creation in Hindu cosmogony (Dimmit & Van Buitenen, 1983). It also may be a mimesis of the Lake Manasarovar lying below Mt. Kailash. The most powerful organizing feature of the city was the precise north–south axis that cuts through the center of the Royal Center and passes over the local manifestation of the cosmic mountain, Matanga Hill (Malville, 1994a, 1994b, 2000; Malville & Fritz, 1993a, 1993b).

Cosmology as Illustrated in the Hindu Temple

The Hindu temple can be used as a mnemonic for a wide range of cosmological concepts of India. Manifesting the parallelism between microcosm and macrocosm, it contains in its center the chaos out of which the universe emerged. Spreading outward along cardinal and intercardinal directions, the stones of the temple are the cosmos into which the universe has transformed itself. The temple is set upon the *vastupurushamandala*, which is the geometric yantra symbolizing the sacrifice and dismemberment of Cosmic Man, Purusha, and the reestablishment of cosmic order. The idea of primordial chaos, which is structured into the center of the temple, is found in many of the cosmological mythologies of the subcontinent and is a well-established feature of the early universe. Creation through disruption of equilibrium, expansion of space-time, and separation of parts are shared concepts of myth and modern cosmology.

The living Indian temple is both a model of cosmos carved in stone and a participatory cosmology. The devotee who enters the temple can travel backward in time by moving from the world of the present, which lies beyond the temple compound, to its center where space and time are collapsed. At the center of the temple, enshrouded by a darkness pierced by only a few lamps, lies the *garbha-gṛha*, the womb chamber symbolic of the chaos, potentiality, and undifferentiated wholeness out of which the universe emerged (Kramrisch, 1946). Spiraling inward in space and backward in time, one proceeds from brightly lighted exterior space of the ordinary world to darkness. The large open spaces of the entrance are replaced by the confined small center; the extravagant richness of carving and decoration turns into the simplicity of the unadorned center. Space is focused like a converging beam of light upon the center, becoming ever more constricted and confined as the garbha-gṛha is approached. It is the center which provides personal renewal and rebirth, paralleling the renewal and rebirth of the universe itself.

The axis of the universe, the axis mundi, passes through these versions of the sacred mountain, and each temple, palace, and city became a connection between the underworld, this world, and the heavens (Eliade, 1963; Bernbaum, 1990). Shamans use that connection as they climb or fly through the worlds. The axis, around which the

Cosmologies of India, Fig. 3 Mt. Kailash

cosmos revolves, is symbolic of the cycles of the heavens, the changing seasons, and renewal of life. Mt. Kailash in Tibet, the most sacred of all mountains in south Asia, is circumambulated, but it has never been climbed. The symbolism of circulation around an axis is repeated in the spinning prayer wheels, which are often carried by Tibetans as they circle Mt. Kailash (Fig. 3).

The superstructure of the Hindu temple, the sikhara, is an explicit metaphor of the cosmic mountain with a cave at its base, establishing the axis and center of the cosmos (Michell, 1988). Often an illusion of height of the sikharas is created by decreasing the spacing of higher features of the tower. Built by the Chola King Raja Raja (985–1014 CE), the 66 m-high sikhara of the Brihadeshwara Temple of Tanjore is one of the highest in India. The dark sanctum at the base of this surrogate cosmic mountain is understood to be the place out of which life emerged (Fig. 4).

Cosmologies of India, Fig. 4 Brihadeshwara Temple of Tanjore, India

Chaos and Equilibrium

"In the beginning was darkness swathed in darkness; all this was but unmanifest water" *ṛgveda* 10.129.3.

The birth of the universe from primordial chaos is one of the most fundamental creation mythologies of our planet (O'Flaherty, 1975). In Hindu cosmology, the metaphors for chaos are water, darkness, disorder, lawlessness, and potentiality. Chaos in the center of the temple is protected by massive stones, priests, and doorway guardians. The garbha-gṛha is the cave in the side of the cosmic mountain, Mount Meru, which

is the axis mundi, connecting heaven and earth. The cave is the womb out of which the world and life have emerged. The small cubical space of the garbha-gṛha is symbolic of the primordial seed of creation. Chaos, as a source of creation, is thus contained, protected, preserved, and intensified in this dark space. The energy of the cosmic cycle is contained in the temple and is available each day of the year for the purposes of cleansing, symbolic death and rebirth, and rejuvenation.

Indra and Vṛtra

The conversion of chaos into cosmos is described in two well-known Hindu myths, the battle of Indra and Vṛtra and the churning of the cosmic ocean. Vṛtra, the Restrainer, held the dark waters of creation tight within his coils and had to be destroyed by Indra in order for the waters of time and creation to flow. The battle between the Aryan war god Indra and his archenemy Vṛtra is rich in thermodynamic meaning. The universe was initially imprisoned as dark and unmoving waters held tightly within the coils of Vṛtra. Actualization of potential inherent in the universe was thus prevented; time could not flow and space could not expand. This metaphor addresses one of the great mysteries of existence: what initiated expansion of space-time? As the god of lightning and thunder, Indra slew Vṛtra with his thunderbolt, the *vajra*. The death of Vṛtra symbolizes the victory of change over stasis, time over eternity, light over darkness, as well as summer over winter. One interpretation of the slaying of Vṛtra is that it is a depiction of the transformation of winter ice into summer waters as the light and heat of the sun destroy the darkness and frozen immobility of winter; the mountain streams, which are held fast in winter's coils, are released to flow to the ocean when winter is conquered by the springtime sun.

The initial symmetry, quietude, and perfect balance of the cosmos were broken when the circular coils of Vṛtra were forced open, and, like the escaping contents of a broken pot, the imprisoned waters of time and change were allowed to flow. The sun and moon, locked as embryos in the dark waters, were born with the death of Vṛtra. The transformation from the state of stasis to that of change involved violent activity, disruption of tranquility, and death of the old.

Churning of the Cosmic Ocean

Thermodynamic elements abound in the story of the churning of the primordial ocean for the purpose of obtaining *amṛta*, the elixir of immortality (O'Flaherty, 1975). Primordial equilibrium, symbolized by the undifferentiated cosmic ocean, was disturbed by the outside agent of the inverted Mt. Mandara, used as a churning stick. In a manner similar to that of the patterns of convection in a heated pot of water, structures hidden in the water were evoked. The cooperation of all aspects of creation was needed for such transformation of chaos: *asuras, devas*, Viṣṇnu who as the cosmic tortoise provided support for Mt. Mandara, and Śiva who drank the poison which emerged before the *amṛta*, the cosmic mountain, and the cosmic serpent, Vasuki. The transformation of equilibrium required extraordinary actions, and the inversion of the cosmic mountain seems to symbolize that ordinary, traditional action was inadequate for such an endeavor. Ordinary action cannot bring about major transformation when powerful self-maintaining cycles, i.e., negative feedback, suppress perturbations. The old standards and ordinary behavior were inverted: Mt. Mandara was converted into a stirring stick, the *asuras* and *devas* cooperated, and the serpent as the churning rope became the agent for change rather than the traditional agent for eternity and stasis. The consequences of the churning were violent: fire, loud noises, upsetting of nature, and death of many creatures. Polar opposites emerged from the waters such as poison and the elixir of eternal life, *amṛta*. All beings and gods were protected from the poison by Śiva who acquired a blue throat while drinking it. Out of the disrupted equilibrium of the ocean emerged the embryonic sun and moon (Fig. 5).

Cosmologies of India, Fig. 5 Churning of the cosmic ocean (Bangkok Airport by Sailko)

Rescue of Earth from the Waters

The story of the rescue of Mother Earth from the waters involves one of the ten incarnations of Viṣṇnu as the boar and is a member of the world-wide class of earth diver creation myths (Long, 1963; *Taittirīya Saṃhita*, *Viṣṇu Purāṇa*: O'Flaherty, 1975). In each of these stories, a creature dives to the bottom of the ocean to retrieve mud which, when brought to the surface, grows to become the planet on which we live. In one version of the Hindu story, there is a violent battle between the cosmic boar and the demon of the waters who, like Vṛtra, has held the earth prisoner, preventing thereby the flow of time. The recurrent symbols of creation in these Hindu myths are again present: formless, rich, and fertile primeval material locked in the eternal, changeless dark waters is released only after a violent struggle. Another important aspect of this myth involves Viṣṇu in his role as expander and extender. After bringing Earth to the surface of the waters, he spreads her out into a flat disk so that, like a lotus leaf, Earth can float on the waters and not sink back to the oblivion of the dark waters and the death of equilibrium. In the astronomical universe, it is the continuing expansion of space-time which causes departures from equilibrium and prevents structures from sinking back into equilibrium.

Primordial Incest

The stories associated with Prajāpati and his daughter, Rohiṇī, form a highly complex collection of symbols involving both sexual and astronomical allusions (Kramrisch, 1981). Back in the timelessness which existed before the creation of our world, the "first created," Prajāpati, desired a second. Instead of a wife, he acquired a daughter with whom he sexually united. The onlooking gods were so outraged by such an unthinkable violation of a fundamental law of nature that they created Rudra, the archer, to prevent and punish the incest of Prajāpati. The arrow shot by Rudra struck Prajāpati, too late, causing him to withdraw from his daughter and spill his seed on the ground. From such an unlikely sequence of actions, human life sprang from the impregnated soil.

> Meant to prevent the act, the flowing of the seed, the shot failed to prevent its consequences. The failure in timing at the dawn of the world was due to time itself, for the latter had not set in as yet; it was just about to begin. The transition from an

> integer without dimension of space and time into existence is a danger zone between eternity and the passing moment... Had the timing been perfect, the flying arrow of Rudra would have prevented the coming into existence of man and the flowing down on the earth of the substance of the Uncreate. (Kramrisch, 1981, p. 26)

The sequence of events can be described in thermodynamic terms as follows. Primordial equilibrium contains within itself processes which may become unstable and grow out of control; the result can be a destruction of the old system and the production of something entirely new. As already mated, an equilibrium system has self-maintaining processes built into it designed to prevent such destruction of equilibrium and stability. Incest as a violation of equilibrium was present in the original plenum of creation. In order to prevent change, a negative feedback loop was created in the form of Rudra to suppress the perturbation. Ironically, the consequence of Rudra's action was the opposite of the original intent. The incestuous act was not punished in a manner such that the original equilibrium could continue, but, quite the contrary, the initial instability grew, life on the earth appeared, and the unchanging primordial state was replaced by time and change.

The Prajāpati myth may have astronomical implications concerning a very early discovery of the precession of the equinoxes. Between 4500 BCE and 3500 BCE at the time of vernal equinox, the constellation which we know as Orion rose heliacally just ahead of the sun. Prajāpati was identified with that constellation (Kramrisch, 1981; Tilak, 1972). Prajāpati was also the year (*Śatapatha Brāhmaṇa 3.2.2.4*) which, exhausted from his labors, needs to start afresh at the time of the vernal equinox. The rejuvenation and rebuilding of Prajāpati, the year, was accomplished symbolically by the construction of the Vedic altar, the bricks of which symbolized the days and seasons of the year. The death of Prajāpati, the old year, was necessary for the continuation of the annual cycle of vegetative life. The symbolism of Orion-Prajāpati rising heliacally on the morning of the vernal equinox may have had great ritualistic significance, announcing by its presence in the equinoctial dawn the time for the rebuilding of the sacrificial altar and the rejuvenation of the exhausted year.

For over a millennium, following 4500 BCE, the constellation of Orion-Prajāpati had provided that announcement. But around 3000 BCE, Prajāpati no longer appeared briefly in the ruddy dawn of vernal equinox, having been replaced due to precession by his daughter, Rohiṇī, the red star Aldebaran, the eye of the modern constellation of Taurus the Bull. The shock of this change in the makeup of the heavens may have been considerable. No longer was the start of the year announced by the heliacal rising of the grouping of stars which had symbolized the year, no longer was there a synchronization of the heavens with terrestrial phenomena and human affairs, and no longer could the heavens be viewed as eternal and unchanging. The astronomical language which is used to describe this event is extraordinary in its allusion to the forbidden act of incest. Prajāpati as the beginning of the year had moved into Rohiṇī due to the process of precession.

A complex variation on the Rudra-Prajāpati-Rohiṇī myth is the story of Dakṣa, the antagonistic and jealous father-in-law of Śiva. The wife of Śiva, Satī, was the first born daughter of Dakṣa. He had 27 other daughters who had been given to the moon in marriage; these are the Nakṣatras, the asterisms through which the moon passes each month in his journey along the sky. Dakṣa performed a great sacrifice but did not invite Śiva nor did he reserve a portion of the sacrifice for Śiva. Dakṣa's jealousy toward Śiva at one level of the myth may symbolize the desire to preserve primordial equilibrium. Satī reproached her father for not having invited her husband. In anger and shame, she committed suicide by throwing herself into the sacrificial fire ignited by her father. Śiva, outraged at the consequence of Dakṣa's insult, came in the form of Vīrabhadra, a fierce manifestation of Śiva. He cut off Dakṣa's head with a sacrificial knife and replaced it with the head of a ram. Vīrabhadra picked up the corpse of his wife and performed a wild and agonized dance with it over the face of the earth. In his dance, his arms flailing to the far

reaches of the universe, the stars were scattered by the sweep of his hair. Fearing that the wild dance, the Tāṇḍava, would destroy the earth, Viṣṇu cut the body of Satī into pieces, and where each piece of flesh dropped to earth, a shrine was built (*Devībhīgavata Purāṇa*: O'Flaherty, 1975). Here again, we encounter the use of horrible and unthinkable mythic deeds to dramatize the consequence of the disruption of cosmic equilibrium and consequent creation in the form of the establishment of shrines and temples across the land.

The Waters and Fires of Chaos

Though structureless themselves, water and fire are infinitely creative (Eliade, 1967). Everything which possesses form has separated itself from water. The gods of chaos must be sacrificed in order for life to appear. When form emerges beyond water, there is a dying of potentiality, and form becomes subject to limitation by the laws of time, change, and decay.

In the temple tank, fed by deep underground springs, lie the dark and murky waters of chaos, reinforcing the meaning contained in the dark sanctum of the temple. Water is a transformational symbol, both life-giving and life-threatening, the source of vitality and creation, as well as the agent for destruction. The waters of the *pralaya*, the cosmic flood at the end of time, provide the source for new creation and new birth. Life is born out of these dark, destroying waters which periodically sweep the earth.

In the city of Vārāṇasī, also known as Kāśī, one finds the intensified symbols of water and fire (Eck, 1983). In the center of Kāśī in the Viśvanātha Temple is the Jyothir liṅga, the great pillar of fire connecting heaven and earth. Near the center is the Maṇikarṇikā *kuṇḍ*, the place of the very first dawn of the world at the beginning of time. In an interesting twist, the *kuṇḍ* associates water in the form of sweat with the act of creation. The *kuṇḍ* was excavated by Viṣṇu using his discus and filled by his sweat before he created the world. Viṣṇu symbolizes the activity, expanding power, and movement of the sun as it traverses the sky with great strides. The discus, which is carried in one of his hands, is a sun symbol (Begley, 1973). Glowing brilliantly, yet terribly dangerous, it is called *sudarśana*, "beauteous sight." The chaos of the earth has thus been disturbed by the sun disk. The water so necessary for creation has come from god himself. Maṇikarṇikā is also identified by local tradition with the jeweled earring of Satī, fallen to the ground while Śiva was performing his dance after her death by fire.

A central theme of Hindu cosmology is the homology of universe and human body, i.e., the body is a microcosm, a model both of the universe but also for the universe. The universe is the dismembered body of Prajāpati and Purusha, the Cosmic Man. It is a complex cosmological homology as, in this view, the human body is both a description of how the universe behaves and a model *for* the universe, i.e., how it should behave. The significance of these "of" and "for" models in cultural symbols has been explored extensively by Geertz (1973). The equality between the sun and the *ātman* which lives in everyone's heart is one such homology. Another homology, suggested by Parry (1981), relates the process of creation and destruction of the universe to the constant stream of sacrificial cremations staged at the Maṇikarṇikā *ghāt*. Parry argues that the human body has been so "cosmicized" in India that the cyclic movement of the entire universe relies upon the unceasing human acts of cremation at Maṇikarṇikā.

The Hindu temple with chaos in its center is surrounded on all sides by the chaos of the profane world; the walls of the temple serve as ramparts against the threatening flood of chaos. Such a flood of chaos can be creative as well as destructive. The devastating flood may be followed by a creative flood as described in the myth of the temple town of Kumbakoṇam:

> When the time of the universal deluge drew near, Brahmā came to Śiva and said, 'Once the world has been destroyed how will I be able to create it anew?' Śiva instructed him to mix earth with *amṛta*, fashion a golden pot, and put the Vedas and other scriptures into the pot along with the Seed of Creation. Brahmā made the pot and decorated it with leaves, and, when the flood began to

> rise, he put the pot in a net bag and sent if off on the waters. Pushed by the wind and waves, the pot floated southwards; the leaves fell off and became holy shrines, and the pot came to rest at a spot proclaimed sacred by a heavenly voice… Śiva took the form of a hunter and shot an arrow, which hit the pot and let loose a flood of *amṛta*. When the waters of the deluge receded, Brahmā fashioned a *liṅga* from earth mixed with *amṛta*, and Siva merged into the lingam in the presence of the gods. (Shulman, 1980)

Creation thus follows the flood of *amṛta*. The creative flood flows because Śiva has broken the restraining pot. Creation thus results from the violent disruption of equilibrium. He repeated the archetypal act of Indra when he slew Vṛtra with his thunderbolt, the *vajra*, and allowed the waters of time and creation to flow. The arrow of Śiva was a shaft of light and time entering the darkness of the watery chaos that existed before creation; the pot was the womb, which releases life.

Other Tamil temple myths echo this theme in which a moving shaft such as a spear plays a crucial role of creation following a flood (Shulman, 1980, p. 73). In over 70 Śaiva temples of Tamil Nadu, the sun penetrates the center of the shrine at sunrise or sunset on a few days of the year near the equinoxes. There are numerous interpretations of the event celebrated as a Sūrya *pūjā*. A popular myth is that Sūrya has become afflicted with leprosy and is requesting that Śiva relieve him of the disease. The reference to leprosy may have been associated with an unusually high level of sun spot activity that we know occurred in the thirteenth century. Another interpretation of the event is that the horizontal shaft of sunlight lighting the Śiva *liṅga* in the otherwise dark *garbha gṛha* is symbolic of the first shaft of light that destroyed the darkness of chaos (Malville, 1985, 2007; Malville & Swaminathan, 1998, 2006).

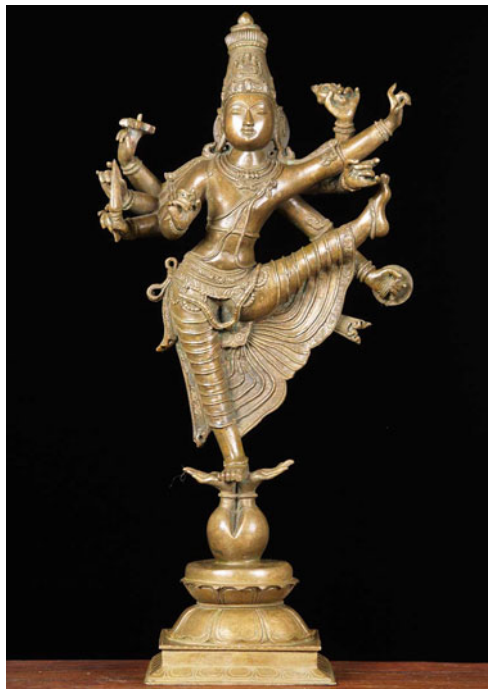
The temple doorway, through which pass shafts of light, arrows of time, priests, and devotees, contains symbols of chaos and water: the marvelous water creature, the *makaram*, with wings of a bird, body of a crocodile, and snout of an elephant, yawns widely on either side. Out of the opened mouth of the *makaram* flow the forms of creation to be reabsorbed at the end of the world age by the opposite *makaram*. Intertwined about the doorway are stalks and leaves of water plants and river goddesses. To pass through the doorway from the profane to the sacred world requires transformation which water provides. The priest when he enters the *garbha-gṛha* experiences a transmutation "promoted by the (water) divinities on the door jambs" (Kramrisch, 1946, pp. 313–314). Coormaraswamy (1980) has written extensively and creatively on the symbolism of this "water cosmology" of India. Upon murky waters floats the white lotus, unpolluted by the mud, a symbol of separation of creation from the waters of chaos. Out of the waters, it climbs on a stalk which is the *axis mundi*, connecting primeval mud with the light of the sun. The earth, the sun, or Brahma is carried by the lotus, suspended above chaos, protected from sinking back into oblivion by the lotus raft. The lotus is also the characteristic symbol of Sūrya, always carried in his hands, expressive of the separation of creation from chaos provided by the light of the sun.

Expansion, Separation, and Differentiation

Nonequilibrium in the universe is the consequence of the expansion of outer space. Portions of the universe were thrown out of equilibrium following the Big Bang as the initially homogeneous matter clumped and hot stars separated from cold space. Expansion is the fundamental dynamic of our universe, constantly forcing matter and energy out of equilibrium and allowing structures to form and complexity to grow.

Viṣṇu as the expanding dwarf who tricked the demon Bali into giving him all the space he could cover in three steps is an oft-repeated allusion to cosmic expansion (*Viṣṇu Purāṇa* 2.36.74-86) (Fig. 6).

As an expanding fish, Viṣṇu saved Manu from a return to chaos through the flood (*Śatapatha Brāhmaṇa* 1.8.1.1-6). When Viṣṇu as the Boar rescued Earth from the bottom of the waters of chaos, he expanded Earth and spread her out, to



Cosmologies of India, Fig. 6 Vishnu, as the expanding dwarf (Kyle Tortora)

prevent her from sinking back again into chaos. The infinitely expanding *liṅga* of fire which confounded Brahmā and Viṣṇu during the darkness before creation as it rose from the cosmic ocean reproduces these resonating symbols of dark waters and expanding form (Zimmer, 1946).

The central tower of the temple, the *śikhara*, the "mountain peak," is another *axis mundi*, which pillars apart heaven and earth and lets creation proceed. In Vedic terms, to separate is to create, and to merge and reabsorb is to dissolve and destroy (O'Flaherty, 1975, p. 125). The myth of the triumphant destruction of the triple cities of the demons by Śiva, as Tripurāntaka, again resonates with the insight that to separate is to create and, conversely, that which causes polar opposites to unite and lose their separate identities is to reverse the course of creation and return to chaos (O'Flaherty, 1975). The triple cities symbolize heaven, earth, and sky and their reabsorption returns the universe to formless equilibrium and chaos.

The symbolism of chariots and wheels is found both in the temple architecture itself and in *ratha* festivals. The temple of Konārak has been fashioned into huge chariot of the sun with 24 wheels pulled forward into the east by seven horses (Malville, 1989; Fig. 7).

The wheel is a preeminent symbol of time with stillness at its center, which allows movement and change. It is also a symbol of sustained separation of the earth and the heavens. The wheels of the sun's chariot are supported and separated by the axle tree, which performs the same function as the *axis mundi*, holding apart the turning wheels of earth and sky. Creation is possible only because of the separation provided by the axle. The wheels are those of Kāla, time, bringing life out of darkness and returning life to darkness and death. The sun god, Surya, is often shown holding lotus flowers in each hand. The lotus, emerging brilliantly white from muddy waters, symbolizes the purity of the sun (Fig. 8).

A frequent icon in many temples is that of Kirttimukha, the "face of glory," another image expressive of creation emerging from separation. Kirttimukha represents both the awesome destructive power of Shiva and the creative powers of the cosmos. Creation flows from his open mouth only so long as it is open; once his jaws close, creation ceases. Fortunately, since Kirttimukha lacks a lower jaw, the mouth of creation can never be closed (Kramrisch, 1946).

The sacrifice of Purusha, Primal Man, contains the three primary cosmological symbols of chaos, separation, and differentiation (*ṛgveda* 10.90.1-16). Primal man represents chaos and infinite potentiality. He must be sacrificed before in order for creation to occur. Like water and fire, chaos and creation, equilibrium and ordered structures are mutually exclusive; once water becomes structured, it is no longer water, but it becomes plants, fish, and people. The strongest image of the sacrifice of Purusha is that of differentiation of the original parts of primordial chaos. Various parts of the body became the infinite variety of the cosmos: the atmosphere, the heavens, and the earth, the creatures of the earth, and the social classes, waters. Prajāpati, also the primal man, "fell apart," separated, and

Cosmologies of India, Fig. 7 Konarak

Cosmologies of India, Fig. 8 Surya

dispersed to become our cosmos: his semen became sun and heaven, his breath became wind and atmosphere, his body became food and earth (*Śatapatha Brāhmaṇa* 7.1.2.1-6).

Symbols of Expansion, Separation, and Differentiation

1. Lotus: separation from mud and water; suspended above chaos
2. Śikhara: separation of earth and sky; expansion upward
3. Tree: expansion downward and upward
4. Gopuras: expand outward and upward from the center
5. Wheels: separated by axle tree
6. Vishnu as dwarf: expanded to step across three worlds
7. Viṣṇu as fish: expanded to save Manu
8. Viṣṇu as boar: expanded earth to prevent it from sinking into chaos
9. Kirttimukha: open mouth allows continuing creation
10. Indra: separates earth and sky by expanding
11. Purusha: separation and differentiation
12. Tripura: separation of the three worlds (Table 1)

Return to Chaos

At the end of a thousand world ages, a day of Brahmā, a Kalpa, the world becomes barren of life. Siva scorches the earth with his eye, drying

Cosmologies of India, Table 1 Hindu cosmochronology (Dimmitt & van Buitenen, 1978; O'Flaherty, 1975)

Yuga	Duration (years)
Kṛta	1,728,000
Tretā	1,296,000
Devāpara	864,000
Kali	432,000
1 Mahāyuga: breath of Brahma	4,320,000
1 Kalpa: day of Brahma	4,320,000,000

up the oceans and rivers. The earth catches fire and burns until it is as bare as the back of a turtle. Then the rains come and pour water on the earth for 100 years, converting the earth into a shoreless ocean. At that time, when only the ocean exists, all creation is absorbed and united into Vishnu who sleeps on his bed of coils of Ananta, meaning infinite, in the darkness of cosmic night (*Viṣṇu Puraṇa*: Dimmitt & van Buitenen, 1978). Over and over, this sequence is repeated without end. Life appears and vanishes as passing days and nights. As in the story of the cities of Tripura which were destroyed when they are brought together by the arrow of Siva, union and absorption mean equilibrium and death.

Our astrophysical understanding of the end of the universe involves death by fire in the collapse of space into a cosmic black hole or death by cold of unlimited expansion. In the more likely future of death by expansion, stars will eventually fall into black holes in the centers of galaxies and the universe becomes a dark and cold system of galactic black holes, silently and darkly revolving one around the other. Even black holes are subject to change, and matter and energy will eventually evaporate from them to produce a return to chaos in the form of a vast expanding ocean of thin, cold light. According to our current understanding, the rate of expansion will accelerate as dark energy pushes our universe apart. Lurking somewhere in the immensity of future time, there must be other universes waiting to be born.

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Prajāpati commits incest: *ṛgveda* 10.61.5-7; 1.71.5; 1.71.8; 1.164.33; Śatapatha Brāhmaṇa 1.7.4.1-8.

Śiva destroys Dakṣa's sacrifice: *Mahābhārata* 12.274.2-58.

Shiva destroys the Triple City of the Demons: *Mahābhārata* 8.24.3-44, 52–124.

The churning of the cosmos ocean to obtain amṛta: *Mahābhārata* 1.15.5-13; 1.16.1-40, 1.17.1-30.

The corpse of Satī is dismembered: *Devībhāgavata* 7.30.27-37, 40–50.

Viṣṇu as a dwarf takes three strides: *ṛgveda* 1.154.1-6; Vāyu 2.36.74-86; Vāyu 2.36.74-86.

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Cosmology in Mesoamerica

Keith Jordan

The Native American peoples who occupied Central and Southern Mexico, the Yucatan Peninsula, Guatemala, Belize, El Salvador, and Western Honduras prior to the Spanish Conquest of the sixteenth century shared many aspects of both material culture and ideology. This cultural unity, underlying varying expressions of the basic pattern across linguistic, ethnic, and political divisions, is the basis for the modern

anthropological construct of Mesoamerica as a distinct culture area. Among the achievements of the pre-Columbian Mesoamerican civilizations of the Aztecs, Maya, Mixtecs, Zapotecs, and others are complex myths and mental maps of the universe as they understood it. These elaborate conceptualizations encompass multiple realms of existence and sequences of creation and destruction across vast epochs of time. While each distinct culture generated its own cosmology, all such models of the nature of the cosmos are united by common features marking them as distinctively Mesoamerican. This entry will employ as representative examples the world views of two Mesoamerican cultures for which much information has come down to us across centuries, the Aztec and the Maya. The reader unfamiliar with the sources and chronology for Mesoamerica should view Extras 1 and 2 before reading further.

Shared Features of Traditional Mesoamerican Cosmologies

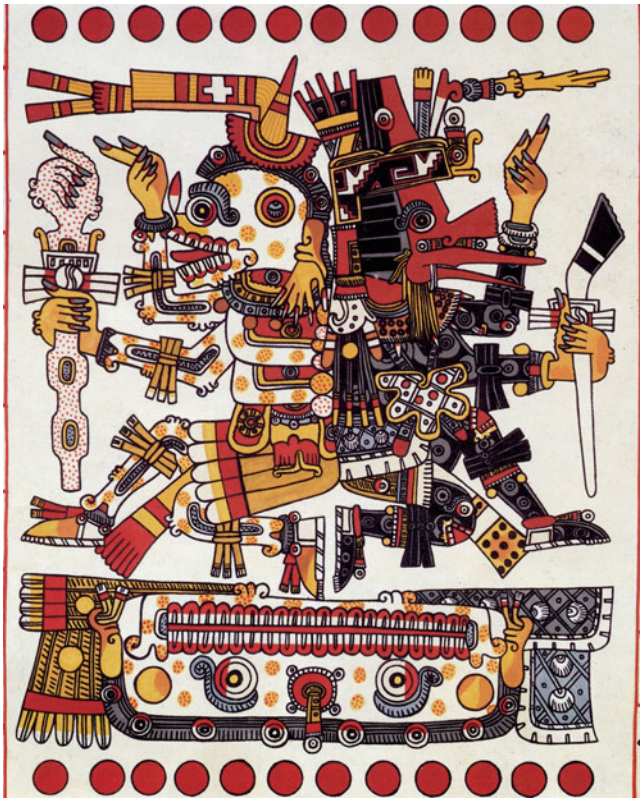
Although details vary across time and political/linguistic boundaries, pre-Columbian Mesoamerican cosmologies share a number of general characteristics. The universe is conceived as arranged in multiple levels, broadly divided into an upper world (the sky), a middle world (the earth), and an underworld beneath the earth. The upper world, home of the gods, may have 13 levels, while the underworld, land of the dead, usually has nine. The earth is pictured as a disc, square, or aquatic reptile floating on the sea. Its surface is divided into four quarters corresponding to the cardinal directions. At its center is a vertical axis symbolized by a tree or primordial mountain, bridging the multiple tiers of the cosmos above and below. This center may be identified with a capital city or sacred site, or with the body of a ruler. Deities, rulers, and ritual specialists use the central axis as a conduit to travel between levels of the universe. Other portals to the ancestral realm of the underworld are depicted as the mouths of mythical reptiles, and equated with caves. Mountains are envisioned as hollow sources of plenty, repositories of water and maize.

Similarities in maps of space are matched by shared, cyclical conceptions of time. The present universe is the last of a series of creations. Each prior cosmos fell victim to catastrophic destruction. A ritual calendar year of 260 days is paired with an approximate solar year of 360 days, a hallmark of Mesoamerican culture (see "► Calendars in Mesoamerica" in this volume). Unlike contemporary Western thought, in the Mesoamerican vision, cosmology is distinguished neither from religion nor from politics. The social order and its activities – like warfare and human sacrifice – are part of the natural order and crucial to the viability of the entire cosmos. The forces that animate and manifest as the phenomena of nature are supernatural beings.

Mesoamerican thought is characterized by dynamic pairings of binary oppositions: male/female; upper world/underworld; rain/dryness; and death/life. Although sometimes labeled as dualism, these conceptions are not dualistic in the Platonic or Manichaean senses, i.e., separating mind and matter. Rather, the opposite qualities interact dynamically and are themselves manifestations of an underlying unity (Fig. 1).

Origins

The beginnings of Mesoamerican cosmology are lost in the distant past. Mesoamerican world views share features with Asian, Native North American, and South American shamanic traditions – e.g., a multilevel universe bridged by a vertical axis conceived as a world tree. Because of these similarities, some scholars trace the roots of Mesoamerican cosmologies back to the presumed shamanistic beliefs of the first settlers of the New World who crossed the Bering Strait or arrived by boat along the Pacific coast during the last Ice Age. Other parallels suggest connections with Asia: the occurrence in both areas of directional symbolism associated with colors, or the identification of the markings on the surface of the moon as a rabbit. However,



Cosmology in Mesoamerica, Fig. 1 Ehecatl/Quetzalcoatl (*right*), a deity associated with life and fertility, and Mictlantecuhtli, god of death and ruler of the underworld, showing duality of opposing forces in the cosmos (Reconstruction of MS painting from *Codex Borgia*, p 56, Mixteca-Puebla style, Puebla/Tlaxcala (Mexico), Late Postclassic. Reconstruction by Gisele Díaz and Alan Rodgers from *The Codex Borgia*: *A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola, NY: Dover, 1993. Reproduced by permission of Alan Rodgers)

the archaeological record does not yield clear evidence for cosmological beliefs in Mesoamerica from the arrival of the first hunter-gathers (pre-10,000 BCE) through the transition to a sedentary agricultural lifestyle (ca. 2000 BCE). The relevance of shamanism to understanding Mesoamerican civilizations has been questioned (Extra 6).

The earliest clear signs of a developed mythic cosmology occur in the monumental art of the Olmec culture of the Mexican Gulf Coast. This civilization, which flourished between 1200 and 400 BCE, has been touted as the "mother culture" of Mesoamerica, although more recent views hold it to be the most developed regional manifestation of a pan-Mesoamerican art style and ceremonial complex. In the absence of readable glyphic inscriptions, reconstruction of Olmec cosmology is a speculative exercise, drawing on inferences from Maya beliefs (see shamanism in Mesoamerica in this volume).

Maya Cosmology

On the basis of artistic, inscriptional and ethnographic data, we know that the Maya of the Classic through Postclassic periods envisioned the earth as a disk or square surrounded by water, or as an aquatic animal, a turtle or a caiman. The earth's surface could be represented as a quadrilateral, based on the traditional Maya maize field or milpa. In the *Popol Vuh* (Extra 5), this shape was mapped out by the gods using a cord during the last creation. This surface was divided into eight by the four cardinal and four intercardinal directions, and transfixed vertically in the center by the world tree, the central axis and path between upper, middle, and lower worlds. This cosmic tree was identified with the ceiba tree, whose sanctity may be related to the resemblance of its sap to blood. In Classic reliefs from Palenque, the world tree is depicted as a cross, with the Celestial Bird, Mut-Itzamna, perched at the top,

and the entrance to the underworld, personified as the skeletal jaws of the White-Boned Serpent or Centipede, gaping at its base. In the sky, the world tree seems to have been equated with the Milky Way, called "the White Road" in Classic texts. Its uppermost terminus was located at the north celestial pole. Deceased souls, along with shamans, move up and down this conduit between cosmic tiers, hence the euphemism for royal death, "he entered the road," in Classic texts. As shamans, Classic kings were supposed to navigate between worlds along the world tree via trance states induced by bloodletting. The king's body itself is symbolically equated in art with this axis mundi.

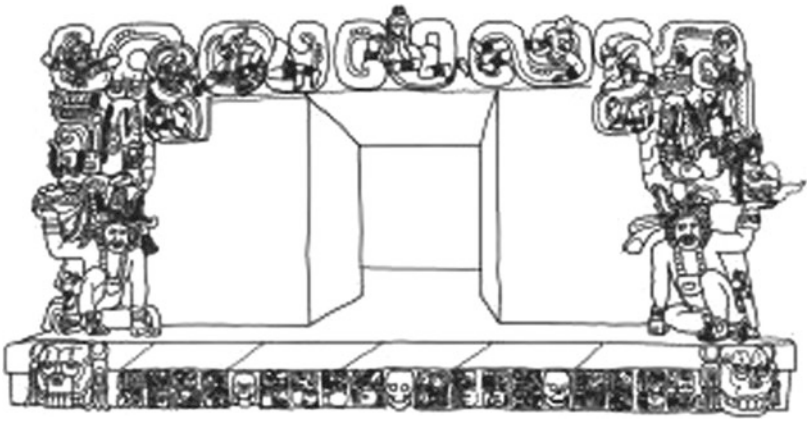
Each of the four cardinal directions was equated with a symbolic color. Red, color of the sunrise, represented the East, a positive direction because of its solar associations. By contrast, West was associated with black and had negative connotations because of its connection with sunset, and by analogy, death. North (white) was the direction of the sun's zenith, followed by dead kings in their apotheosis to the celestial world (Extra 7). It was the domed house of the sky, raised by the Maize God during the last creation of the world. South (yellow) pointed to the depths of the underworld. The earth was supported by four beings referred to as Bakabs or Pauhatuns. According to the *Chilam Balam of Chumayel* (Extra 5), they were survivors of the destruction of the third creation. In other sources, they are the winds. The Maya rain god, Chaak, is also depicted with four manifestations corresponding to the cardinal directions.

Below the earth lay the nine-tiered underworld, Xibalba, "place of fright." This underwater realm was pictured as dark, foul, cold, associated with disease, death and rot, home of monsters and malevolent gods like the Lords of Death named in the *Popol Vuh* by such epithets as "Pus Master" and "Stab Master." Xibalba rotates over the earth at night to become the night sky. Caves, the jaws of the earth, were entrances to Xibalba, paths taken by the setting sun as it entered the underworld. At the same time, caves carried connections with fertility, being the source of rain, clouds, and maize. Another type of cosmic portal, perhaps a manifestation of the *axis mundi*, is represented in Classic art by supernatural snakes, Vision Serpents. These entities, brought into transient existence by the bloodletting rites of Maya kings, serve as bridges between the rulers and the realm of their ancestors, who are seen emerging from the serpent's jaws to bestow their blessings (Figs. 2 and 3).

The upper world, with its 13 levels, was represented in art by the Skyband, a two-headed serpent or crocodile symbolizing the ecliptic. The serpent image may be a visual pun: in the Cholan Maya language, *kan* (snake) resembles *can* (sky). Skybands were used as borders demarcating the upper world in art. The ecliptic can also be represented as a cord which guides the celestial bodies across the sky. The daytime sun was represented by the male deity, Ah Kin or Kinich Ahau. At night, the sun passed through Xibalba, where it took the form of the Jaguar God of the underworld (although an alternate interpretation connects him with the moon). The moon could be represented by a goddess, often depicted as a youthful seductress, accompanied by the rabbit that was seen in its features. Lunar eclipses, recorded and predicted with accuracy, may have been the preserve of a separate divinity (Figs. 4, 5, and 6).

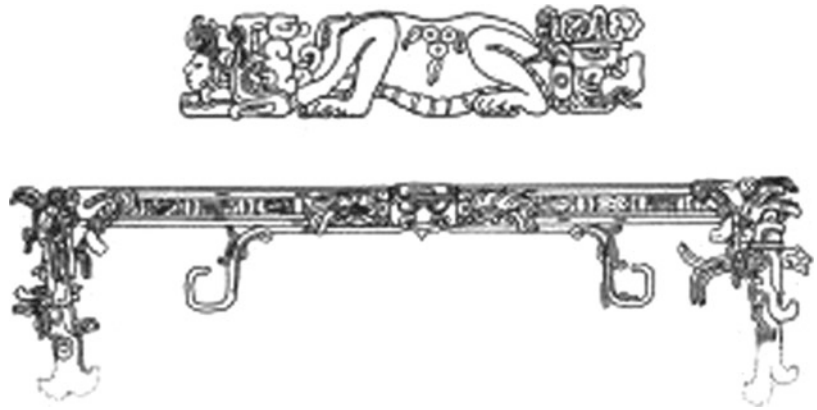
The Maya also charted the movements of Venus. As in other parts of Mesoamerica, this planet was associated with warfare. It is possible that military engagements were timed in the Classic period according to the planet's 584-day cycle, though recent epigraphic work suggests that more pragmatic factors no doubt also influenced such decisions. In the *Popol Vuh*, Venus is depicted as carrying the sun. The Maya kept track of the behavior of other planets visible to the naked eye, but our understanding of their planetary symbolism remains uncertain. For example, Mercury may have been identified with the deity Kawil, whose reclining posture may reflect the planet's observed position just above the horizon, but another interpretation links the same deity to Jupiter.

The stars were set in motion by the raising of the world tree at the last creation. Maya conceptions of the zodiac and constellations remain poorly understood. It appears that the Pleiades

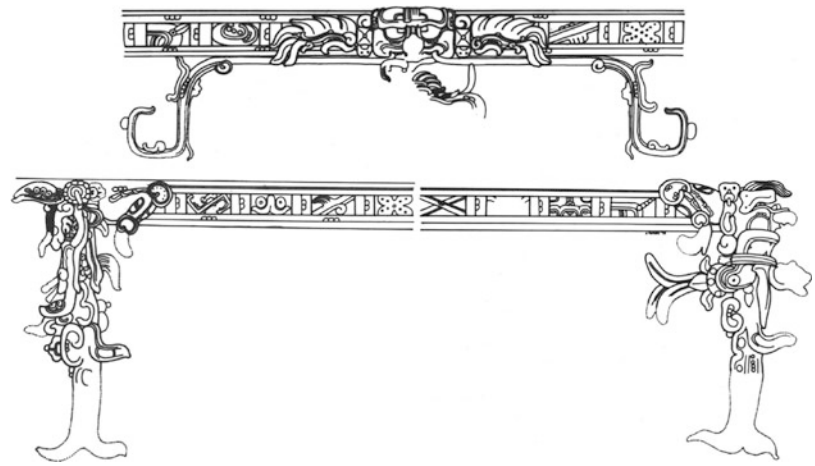


Cosmology in Mesoamerica, Fig. 2 Doorway of Temple 22, Copan, Honduras, Late Classic Period. The decoration of this temple structure symbolizes the Maya cosmos. At the *top*, the serpentine Cosmic Monster represents the sky. The crouching figures on either side of the entrance are bacabs or pauhtuns, the deities who support the world. The skulls at the base represent the underworld. The doorway itself represents a symbolic cave, entrance into the underworld. When the Copan ruler Waxaklahun Ubah Kawil (18 Rabbit), who commissioned the structure, entered the temple he was symbolically entering a portal to the supernatural world of his ancestors (Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan))

Cosmology in Mesoamerica, Fig. 3 Vision Serpents, Late Classic. Detail of two vision serpents with ancestors emerging from mouth and two double-headed serpent bars with deities emerging from opened mouths (Drawing/text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI)



Cosmology in Mesoamerica, Fig. 4 Classic Maya Sky Serpents. Two variants of the double-headed serpent representing the ecliptic. *Top*: legged variant, Altar 41, Copan, Honduras. *Bottom*: stucco relief sculpture from House E of the Palace at Palenque, Mexico (Late Classic, ca. 600–800 CE) (Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan))



Cosmology in Mesoamerica, Fig. 5 Skybands from Palenque, Late Classic Maya. Reconstruction of stucco relief sculptures from "bicephalic Room," House E, Palace. The *top* drawing shows the Celestial Bird and skyband, from the north wall. The *bottom* drawing represents a second two-headed deity, a composite of skyband segments from the west and east walls. The skyband on the Western wall has a saurian or reptilian head with Venus markings (Drawing/text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI)

were envisioned as a rattlesnake (*Sab*), while the belt of Orion was equated with a turtle (*Ak*), through whose shell the Maize God resurrected at the last creation (Extra 7). Alternatively, *Ak* may correspond to Gemini, and the Pleiades were also identified with 400 boys killed by the monster Zipacna, an event placed by the *Popol Vuh* shortly before the last structuring of the world. A scorpion constellation may be identical to Scorpio, or correspond to Gemini. Mut-Itzamna, avian shamanic alter ego of the sky deity Itzamna, seems to have been identified with the Big Dipper.

For the Maya, the present universe is the most recent of cyclic creations destroyed by past catastrophes. The last reordering of the cosmos occurred in 3114 BCE, the mythic starting point of the ▶ Long Count dating system (Extra 6).

Cosmology in Mesoamerica, Fig. 6 Paddler Sun, Early Classic Maya. Drawing of lidded four-legged vessel. Each of four legs represents a downward facing peccary. Atop the lid, the Sun God, wearing a cap marked with k'in ("sun") paddles his canoe through a watery environment containing fish. This vessel has been interpreted as representing the Sun God paddling his canoe across the ecliptic and the constellation of Gemini (Drawing/text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI)

According to an inscription in the Temple of the Cross at Palenque, the creator deities First Mother and First Father (the Maya Maize God) set three hearth stones at the center of the universe, identified with the stars Alnitak, Saiph, and Rigel. As the sky lay flat upon the earth, the Maize God lifted it up to its present position, supported by the world tree. This ordering of the cosmos set in motion time and the movements of the stars.

In the *Popol Vuh* creation myth, the gods of creation reside in watery chaos, silent and dark. They create the first version of the universe, populated by animals, but are unsatisfied because the beasts are incapable of worshipping their makers. To rectify this deficiency, the gods create the second world and make the first humans out of mud. However, these creatures were incapable of thought, and the gods destroyed them and their world by water. On the advice of an elderly couple skilled in divination, the gods created the humans of the third creation out of wood. These people were able to speak, but had no emotions, and did not recognize the gods as their creators. This failed experiment was brought to an end by a flood and rain of pitch. The few surviving wooden men were transformed into monkeys.

Order was brought out of the chaos left by the flood by the erection of the vault of the sky and separation of the earth from water. The gods created the current race of humans from maize, but they proved to be too smart for their creators' liking. As a countermeasure, the gods limited their understanding. From the interior of the terrestrial cornucopia, First True Mountain, came seeds, maize and water for the sustenance of humanity.

Aztec/Nahua Cosmology

The Mexica, or Aztecs, and related peoples of Postclassic Central Mexico, envisioned the universe as a fluxing reality permeated with spiritual forces in endless transformation. Like the Maya, they seem to have believed in an upper world of 13 levels and an underworld of nine, though this conclusion, based on colonial sources, has been questioned. The earth was pictured as a disk or a floating crocodilian or toad-like monster, Tlaltecuhtli, bounded by a square or circle of water joined to the vault of the sky. For the Aztecs, the central axis connecting the three realms of the universe transfixed the earth at their capital city, Tenochtitlan, on the site of the Templo Mayor (great temple). As in Maya cosmology, the world was divided by the four cardinal directions. East, associated with solar hues of red and yellow, was viewed as positive. North was referred to as the Land of the Dead, as it was believed that the journey of souls to Mictlan, the underworld, began here. It was cold and its color

Cosmology in Mesoamerica, Fig. 7 Detail of ceremonial mosaic shield interpreted as representing the central axis of Aztec cosmology. A world tree sprouts on the upper level, the sun symbol with the four directions and the center laid out in a quincunx pattern decorates the middle level. A serpent spirals through the four layers of the cosmos (Drawing/text by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI)

was black. West, the Region of Women, was associated with the positive colors, blue and green, while South, called the Region of Thorns, was symbolized by white. Each direction had its own version of the rain god, Tlaloc, in a similar fashion to the Maya Chaaks. A slightly different Nahua conception of directional symbolism, probably produced in Puebla or Tlaxcala, is illustrated in Extra 8 (Figs. 7 and 8).

On the earth's surface, mountains were hollow repositories of water and clouds, entrances to Tlalocan, the paradise of the rain god. The mythical Mountain of Sustenance was the source of maize, from where it was stolen by the god Quetzalcoatl at the last creation for the benefit of humans. Rivers and caves were the hungry orifices of the Earth Monster, who bore crops for human survival but devoured humans when they returned to the earth at death (Fig. 9).

The upper realms included the paradise of the sun, to where the souls of warriors slain in battle or captured and sacrificed, and of women who died in childbirth, ascended after death. They were privileged to accompany the sun on its daily journey across the sky. Tlalocan was another celestial paradise where the spirits of humans who died by drowning, lightning, or diseases associated with water went to spend the afterlife in joy. The uppermost heaven belonged to the primordial couple, the creator deities Ometecuhtli and Omecihuatl. The sun was represented by the god Tonatiuh, and also equated with the Aztec tribal patron, the war god Huitzilipochtli. As among the Maya, Venus had a malevolent role among the heavenly bodies. The god of Venus as the Morning Star, Tlahuizcalpantecuhtli, is represented in the Borgia group of manuscripts with a skeletal mask, hurling darts at his victims. This deity was a manifestation of Quetzalcoatl. It is commonly repeated in the literature that another form of Quetzalcoatl, the dog god Xolotl, represented Venus as the Evening Star. Meteorites were equated with caterpillars and worms and were referred to as the excrement of the stars. Some stars were *tzitzimime* – demons who will devour humans at the end of the present creation. The Milky Way was represented as a divine couple, Citlaltonac and Citlalicue (Fig. 10).

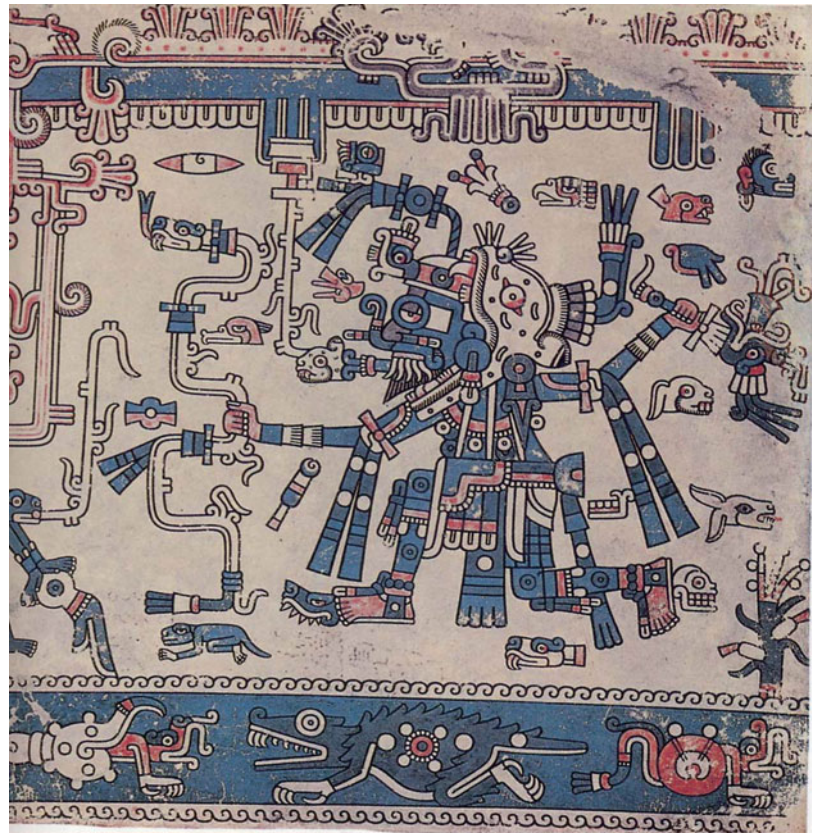
At the nadir of the underworld was Mictlan, land of the dead, destination of those souls who did not die in battle or by sacrifice. This was a shadowy half-world much like the Greek Hades, where the dead were not tormented but faded into

Cosmology in Mesoamerica, Fig. 8 The five directions of the Nahua cosmos: the four cardinal directions and center, with deities. *Clockwise from top right*: sun god, patron of the East; Tlaloc, god of rain, patron of the South; Xipe Totec, Our Lord the Flayed One, god of agricultural fertility and patron of the West; Mixcoatl, god of hunting, patron of the North (Reconstruction of MS painting from the *Codex Borgia*, p 25, Mixteca-Puebla style, Puebla/Tlaxcala region, Late Postclassic. Reconstruction by Gisele Díaz and Alan Rodgers from *The Codex Borgia*: *A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola: NY: Dover, 1993. Used by permission of Alan Rodgers)

nonexistence. It was reached by the soul after an arduous journey through bitter cold and obstacles like wind-blown knives. A dog was sacrificed and included in burials to help the departed navigate this difficult passage.

The Aztecs saw the present world as the fifth in a series of successive creations, or Suns, brought to an end by a series of destructions. According to one commonly repeated variant of the creation myth, the first world, Four Jaguar, was created out of primordial chaos, and ruled over by Tezcatlipoca, the protean god of kingship, fate, the night, and sorcery. The first created humans were giants – the Aztecs identified the bones of mastodons as their remains. At the end of this era, jaguars devoured these primal men. This catastrophe coincided with the defeat of Tezcatlipoca by his rival, Quetzalcoatl, god of the wind, fertility, and a culture bearer for later humans. The second creation, Four Wind, was effected and ruled by Quetzalcoatl in his manifestation as the wind, Ehecatl. In turn, he was defeated by Tezcatlipoca, and his world and its humans wiped out by hurricanes. The few survivors became monkeys. Tlaloc governed the third world, Four Rain. This creation was brought to a violent end by fire and water, and the survivors became dogs, turkeys, and butterflies. Four Water, the fourth world, appropriately had Chalchiutlicue, goddess of ground water, as its patron. Fittingly, Four Water was destroyed by a flood; its human survivors were changed into fish (Fig. 11).

After the destruction of four Water, Quetzalcoatl and Tezcatlipoca collaborated to raise the sky from the earth, supported on the trees of the four directions. The Milky Way marks their path where they walked across the new sky. A crocodilian monster, variously identified as Tlaltecuhtli or Cipactli, was vanquished by the two gods and split in half to become the earth. The gods altered her body to yield crops for



Cosmology in Mesoamerica, Fig. 9 Tlaloc, god of rain, thunder, and lightning (MS painting from *Codex Laud*, p 45, Mixteca-Puebla style, Puebla/Tlaxcala region, Late Postclassic. Reproduced from Gordon Brotherston, *The Painted Books of Mexico*. London: British Museum Books, 1995, Fig. 148, p 135. Reproduced by permission of Gordon Brotherston)

humans, but in her pain, she required blood sacrifice in return for her bounty. Quetzalcoatl retrieved by trickery the bones of past humans from Mictlan to create new humans. He animated them by letting his own blood, another reason for offering blood sacrifices to the gods in gratitude. The gods assembled at the ancient city of Teotihuacan, to sacrifice themselves to create the Fifth Sun and start its motion across the sky. A disfigured god, Nanahuatzin, ("the purulent one"), sacrificed himself by immolation and became the sun. The future moon, who had hesitated to volunteer his life, followed Nanahuatzin's example and emerged from the flames as brilliant as the sun. The other gods, remembering his cowardice, dimmed his brilliance by striking him in the face with a rabbit, leaving the pattern visible still on the moon's surface.

This present Sun, Four Movement, will be destroyed by earthquake. In the hopes of delaying this catastrophe, the Aztecs found further justification for human sacrifice on a grand scale to strengthen and nourish the cosmos.

Extra 1: Historical Time and Space in Mesoamerica

The indigenous peoples of Mesoamerica, like all other Native Americans, are the descendants of migratory hunter-gatherers who arrived in the New World from northern Asia by 12000 BCE, and perhaps considerably earlier. By 2000 BCE, the first Mesoamericans had developed a system of agriculture based on the staples of beans, squash, and most important, maize. This shift in economy led to the rise of permanent village communities and increasing levels of social stratification and cultural complexity.

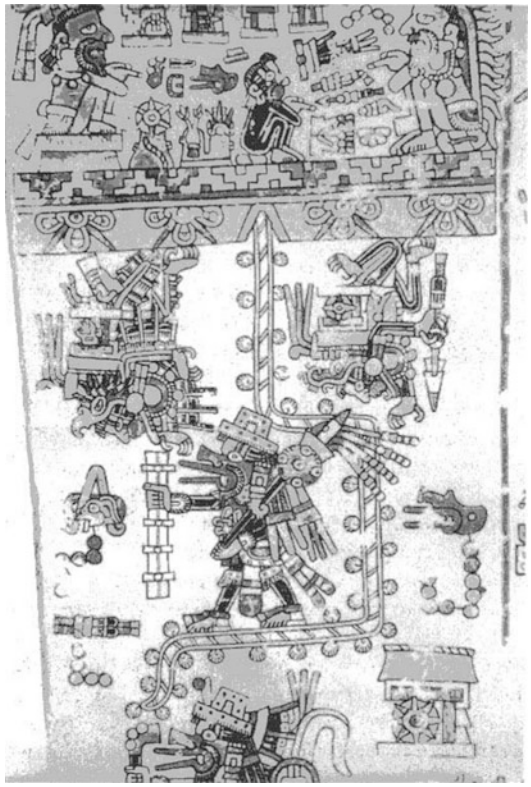
By 1500 BCE, hierarchical societies with sophisticated cosmologies, monumental

Cosmology in Mesoamerica, Fig. 10 Tonatiuh, the Nahua sun god (*left*), and the moon with rabbit (*upper right*) (Reconstruction of MS painting from *The Codex Borgia*, p 71, Mixteca-Puebla style, Puebla/Tlaxcala region, Late Postclassic. Reconstruction by Gisele Díaz and Alan Rodgers from *The Codex Borgia*: *A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola, NY: Dover, 1993. Reproduced by permission of Alan Rodgers)

architecture, urban settlements, and specialized artists had emerged along the Mexican Gulf Coast in the modern Mexican states of Veracruz and Tabasco, and in the highlands of Chiapas and southern Guatemala.

Mesoamerican scholars traditionally used the term "Preclassic" or "Formative" to refer to the period from these first manifestations of civilization down to the third century of the Christian era. This terminology is an artifact of the historical development and biases of Mesoamerican studies over the last 200 years. Because Maya art is relatively naturalistic and reminded nineteenth and twentieth century archaeologists of the Classical styles of the ancient Mediterranean, it was given a privileged status relative to the rest of Mesoamerican art. This, and Maya achievements in mathematics, astronomy and the calendar, led early scholars to equate the apogee of Mesoamerican civilization with the period when the Maya erected cities and monuments dated by hieroglyphic inscriptions using the ► Long Count system. This time interval, ca. 250–900 CE, thus became the Classic Period, and rather predictably, the periods before and after it became the Preclassic (1200 BCE–250 CE) and Postclassic (ca. 950 CE–1521). During the Classic, it was alleged, the Maya and other Mesoamerican civilizations were governed by theocracies of astronomer priests and lived in utopian peace, free from conflict. During the Postclassic, the political and social order found among the societies encountered by the sixteenth century Spanish, based on war, human sacrifice, and monarchy, supposedly eclipsed this priestly paradise.

Discoveries in archaeology and epigraphy during the second half of the twentieth century have shattered the illusion of a Classic period



Cosmology in Mesoamerica, Fig. 11 Nine Wind, the Mixtec equivalent of Quetzalcoatl, descending from the heavens (MS painting from the *Tepexic Annals*, *Vienna Codex*, p 5, Late Postclassic. Reproduced from Gordon Brotherston, *The Painted Books of Mexico*. London: British Museum Books, 1995, Fig. 141, p 127, by permission of Gordon Brotherston)

governed by pacifist stargazers. It is now clear that the Classic civilizations, especially the Maya and the city of Teotihuacan in the Basin of Mexico, were engaged in warfare and human sacrifice on a large-scale, and that the Classic Maya were ruled by kings who were as much politicians and warriors as they were priests. It is also apparent that Mesoamerican civilization did not "degenerate" after the Classic period. It merely changed in directions that did not suit the prejudices of early pundits. But the chronological system has remained in use, despite proposed alternatives. The Preclassic, however, is now generally referred to as the Formative, in an attempt to characterize it based on its own characteristics – the formation of the general Mesoamerican cultural pattern – rather than by comparison with the Classic.

The Formative Period is in turn divided into three stages. During the Early Formative (ca. 1500–900 BCE), Olmec civilization flourished on the Gulf Coast around the site of San Lorenzo, while chiefdoms in Oaxaca, Chiapas, and southern Guatemala participated with the Olmec in a system of trade and shared ideologies among elites. During the Middle Formative (ca. 900–300 BCE), San Lorenzo collapsed, and Olmec civilization became focused on other sites like La Venta. Elite centers as far away as the Mexican states of Guerrero and Morelos shared symbolism and perhaps even artists with the Gulf Coast. In Oaxaca, the Zapotec people founded the great city of Monte Alban, where the first evidence of the distinctive Mesoamerican calendar system appears. In the Maya region, urban centers with monumental architecture appear in both the highlands and lowlands of Guatemala.

By the Late Formative (300 BCE–250 CE), the Olmec culture declined and vanished from the archaeological record. In the central highlands of Mexico, the huge metropolis of Teotihuacan emerged as a major power with influence felt throughout Mesoamerica. In Veracruz and Chiapas, the oldest known inscribed dates in the Long Count come from this period. In the Maya region, huge cities rivaling their "Classic" descendants were raised at sites like El Mirador in Guatemala, and the ideology of Maya kingship began to take shape.

The Classic Period is usually divided into Early and Late phases. During the Early Classic (ca. 250–600 CE), Teotihuacan reached its peak of political, religious, and artistic influence on the rest of Mesoamerica, even apparently interfering in the political affairs of distant Maya city-states like Tikal, Guatemala. In the Maya area, fully developed hieroglyphic inscriptions appear. Centers like Tikal and Copan rose to political prominence and artistic glory. In Oaxaca, the Zapotec capital of Monte Alban reached its florescence. The Late Classic saw the full cultural and political development of Maya cities such as Tikal, Copan, Palenque, Yaxchilan, and Piedras Negras. In Central Mexico, Teotihuacan's sacred center

was burned and abandoned, ending the city's dominant position, while other centers like Xochicalco and Cacaxtla flourished in its wake. Long-distance trade contacts are revealed by the eclectic art of these sites, showing influences from as far away as the Maya.

By 900 CE, most of the southern Maya cities were abandoned after overpopulation, soil exhaustion, drought and warfare led to the breakdown of the Classic Maya institution of kingship. No more ► Long Count dates were recorded. In Yucatan, however, Maya centers like Uxmal and Chichen Itza continued to thrive, the latter perhaps for several centuries. In Central Mexico, a multiethnic people, the Toltecs, established their capital at Tula in the modern state of Hidalgo, marking the transition to the Early Postclassic (950–1150 CE). In Oaxaca, the warring Mixtec dynasties described in their screenfold books began their rise to power. An art style or group of related styles, usually called "Mixteca-Puebla" after the two regions believed to be its place of origin, became an international visual language among Mesoamerican elites.

In 1168 CE, Tula was sacked and burned by invaders from the north, an event sometimes used to mark the inception of the Late Postclassic. In Yucatan and Guatemala, the Maya split into small warring polities. In Central Mexico, a certain degree of political unity was brought about by the Mexica or Aztecs. Originally from the north, the Aztecs migrated into the Basin of Mexico and founded their capital city of Tenochtitlan on the site of modern Mexico City, in the early fourteenth century. Within less than two centuries, they had established a system of tribute states, often erroneously labeled an empire, west into Guerrero, south into Oaxaca and Chiapas, and east to the Gulf Coast. The arrival of the conquistadors in 1519 brought Aztec hegemony – and native rule of any kind in central Mexico – to an abrupt end. By 1521, Tenochtitlan had been destroyed and Mexico became the Viceroyalty of New Spain. The Maya, less centralized, and with less gold to attract the attention of the invaders, held out longer. Yucatan was not firmly under Spanish control until the 1540s, and the last autonomous Maya kingdom, Tayasal in Guatemala, was able to maintain its independence until it finally fell to Spanish forces in 1697.

Extra 2: Sources and Their Problems

Our knowledge of prehispanic Mesoamerican world views derives from several sources via which evidence of cosmological beliefs has survived both the ravages of time and the impact of the Spanish Conquest of the sixteenth century. Yet, each line of evidence is marked by ambiguities and gaps in information, simultaneously preserving and obscuring pre-Columbian conceptions of the universe. From the period of initial Spanish contact with Native Mesoamericans, we have written documents, chronicles, and letters by conquistadores and missionaries. In particular, the writings of Duran and Sahagun on the Aztecs, and Landa on the Yucatec Maya, have preserved much information about Mesoamerican cosmology in the sixteenth century. However, Colonial accounts of indigenous beliefs are frequently incomplete, propagandistic in their efforts to justify conversion of the "idolatrous" natives, and distorted by the conceptual frameworks of their authors. Western assumptions are forced onto very different views of the cosmos, leading to debate and uncertainty for centuries to come (Extra 3: Did Mesoamericans Have Gods?). In addition, the validity of using these late traditions to interpret the beliefs of earlier Mesoamerican civilizations is limited, since systems of thought rarely remain static for centuries. Many attempts to "read backwards" from colonial sources to interpret earlier belief systems founder on the uncertainty created by such large gaps in time.

At the same time as they were preserving aspects of Mesoamerican cosmology in their writings, the friars of the sixteenth century were busy destroying another type of evidence – indigenous screenfold books. Many of these documents, painted on bark paper or deer skin, were burned by the colonists in their zeal to destroy Native Mesoamerican religions. Few have survived as a result (Extra 4). These painted

books contain scenes illustrating episodes from cosmogonic myths, symbolic maps of the universe, and astronomical observations. Unfortunately, they are frequently fragmentary or poorly preserved. Without surviving oral tradition, their imagery is often difficult to interpret, and owing to their fragility, only examples from the centuries immediately preceding European contact have endured.

Over the last half century, epigraphers have made tremendous progress in deciphering Maya hieroglyphs. These advances have led to increased understanding of Maya cosmology during the Classic Period (ca. 250–900 CE) on the basis of inscribed texts. However, work in this field is still in an early, rapidly developing stage, with the result that newly published translations are often provisional and sometimes quickly superseded – hallmarks of a discipline in flux.

Art historians have contributed to our comprehension of pre-Columbian conceptions of the cosmos through interpretations of iconography. While their work has led to the recognition of cosmograms, astronomical symbols, and creation myths in Mesoamerican art, it is frequently speculative and controversial. In particular, attempts to interpret the religious art of earlier cultures by using Conquest-era sources are fraught with uncertainty, as noted above. In a similar fashion, archaeology has played its role in the recovery of ancient Mesoamerican world views via careful excavation of monuments and art as well as traces of ritual behavior. But again, interpretation of the data in the absence of written texts or clear-cut continuities with historic observations remains limited by the incomplete nature of the archaeological record. The looting of archaeological sites, leading to the appearance on the art market of artifacts orphaned of their context, has further contributed to the loss of information.

A hybrid discipline, called archaeoastronomy in the US and astroarchaeology in Britain, arose in the 1970s out of collaboration between archaeologists and astronomers. It focuses on ancient knowledge and practice of astronomy as revealed by site orientations, building alignments, and visual images. In Mesoamerica, it has elucidated the understanding and observation of celestial phenomena in pre-Conquest times, frequently working in close conjunction with epigraphy and archaeology.

Traditional Mesoamerican cosmologies are by no means dead systems confined to the past. Indigenous conceptions of space, time, and creation persist among some of the present-day descendents of the pre-Columbian peoples, notably Maya groups in rural Guatemala and Chiapas, and the Mixtec of Oaxaca. Historic and contemporary ethnographic data have been used to clarify prehispanic beliefs, although again caution is needed when extrapolating meanings from the present to the past across centuries marked by the disruption of colonization and the influence of Christianity (Extra 5).

Extra 3: Did the Ancient Mesoamericans Believe in Gods?

The sixteenth century missionary friars who recorded accounts of Mesoamerican religions for the ultimate aim of destroying them, imposed preconceived frameworks derived from the classical Mediterranean and Judeo-Christian traditions onto the alien belief systems they sought to understand. Faced with images and stories of a myriad of supernatural forces, the colonial writers classified these mythic entities along the lines of the Greco-Roman pantheon of deities, each a discrete being with clearly distinguished personality, function, and symbols. The limits of this approach led to strange contradictions from the start. For example, the mercurial Aztec deity Tezcatlipoca, associated with both kingship and sorcery, was equated by the Spanish chroniclers with both Jupiter and Lucifer. However, the Eurocentric assumptions behind such taxonomies remained unquestioned until well into the twentieth century (Fig. 12).

In the 1970s, a number of scholars began to argue from closer reading of colonial sources as well as the results of archaeological, ethnographic and art historical research, that the Aztec, Maya, and Zapotec peoples had no conception of separate and distinct gods. Rather, what the Spaniards erroneously interpreted as a

Cosmology in Mesoamerica, Fig. 12 Tezcatlipoca, (Reconstruction of MS painting from the *Codex Borgia*, p 17, Mixteca-Puebla Style, Puebla/Tlaxcala region, Late Postclassic. Reconstruction by Gisele Díaz and Alan Rodgers from *The Codex Borgia*: *A Full-Color Restoration of the Ancient Mexican Manuscript*. Mineola, NY: Dover, 1993. Used by permission of Alan Rodgers)

well-defined pantheon was in fact a series of overlapping symbolic complexes, representing natural phenomena conceived as protean and fluxing manifestations of a generalized notion of holiness or sacred force. The words employed for this dynamic concept – *teotl* in Nahuatl, *ku* in Maya, and *pee* in Zapotec – had been translated as "gods" by the Spanish.

Some modern writers – most notably the American anthropologist Joyce Marcus – have argued the extreme conclusion that ancient Mesoamericans had no gods at all, just symbols of natural phenomena and venerated ancestors. This interpretation in its strictest sense certainly applies to some alleged "deities." The Maya icon designated "God C" by the nineteenth century scholar Schellhas in his attempt to classify the supernatural images in Maya codices is now generally accepted by epigraphers and art historians to denote a general quality of holiness rather than a specific divine personality. On the other hand, it seems clear from recent hieroglyphic decipherments that the Classic Maya did believe in a series of relatively separate gods whose acts are recorded in texts and whose distinctive emblems appear in art. While more fluid and dynamic in their identities than the denizens of Olympus, these entities can be usefully conceptualized as gods, a view argued by the American anthropologist and iconographer Karl Taube, among others.

Extra 4: Mesoamerican Screenfold Books

At the same time as they were creating one source of evidence for prehispanic Mesoamerican cosmologies via their writings, the Catholic missionaries of the Spanish Conquest were busy destroying another – the screenfold books of the indigenous peoples. These fragile testimonies to Native American thought were burnt as symbols of the "heathenism" or "diabolism" that the friars sought to replace with forced conversion to Christianity. As a result of this holocaust of texts, very few of these manuscripts have survived to receive the attention of modern anthropological, epigraphic, and art historical study.

Mesoamerican folded manuscripts, often referred to in the literature by the Eurocentric term "codices," consisted of long sheets of beaten bark paper or (in the Mixtec area) deer skin. Narrative scenes, deity images, and glyphs were painted, usually in polychrome, on a thin outer surface of plaster. The paper was folded like an

accordion, dividing it into "pages" or "folios." The resultant manuscript was "opened" by unfolding it.

No prehispanic Aztec painted books survived the depredations of the colonial clergy. A manuscript illustrating Aztec deities and calendrical practices, the Codex Borbonicus, was once thought to represent such a miraculous survival, but art historical data now suggest a date early in the colonial period. From this transitional epoch, we have several manuscripts, in both screenfold and European bound formats, commissioned and annotated by Spanish officials and missionaries but painted by Aztec artists. Frequently, the style is a fusion of pre-Conquest traditions with varying admixtures of the visual language of European Renaissance art. Some of these books preserve Aztec myths and calendric information, albeit incompletely.

A group of screenfold manuscripts of late prehispanic (Late Postclassic) date have been labeled the Borgia Group because of their stylistic affinities with the best-known example, the Codex Borgia. These manuscripts appear to have been collected at the time of the Conquest and to have found their ways by often untraceable routes into famous European collections, hence their names. In the opinion of the majority of art historians and anthropologists, this group was painted in the present-day Mexican states of Puebla and Tlaxcala, though a small scholarly contingent still suggests a Mixtec origin. They are frequently labeled as "Aztec" in the popular literature. If the dominant theory is correct, the artists who created these works spoke the same language as the Aztecs (Nahuatl) but were politically and ethnically distinct. The Tlaxcalans, in particular, were the traditional enemies of the Aztecs and assisted Cortes in his destruction of Aztec power. The manuscripts of the Borgia Group seem to have been guides for a divination system based on the 260-day ritual calendar, also containing prescriptive representations of other rituals, astronomical information, and narrative scenes of mythic events in a distinct style characterized by bright, flat colors, bold outlines, and cartoon-like exaggerations of distinguishing features and costume elements. Their symbolic maps of the universe – like the frontispiece of the *Codex Fejervary-Meyer* reproduced here – constitute excellent graphic evidence for ancient Nahuatl cosmology.

Another group of screenfold manuscripts collected during the Spanish invasion and scattered through European collections was produced by the Mixtec in what is now the Mexican state of Oaxaca. Although the style has similarities to that of the Borgia group, the content consists mostly of historical and genealogical narratives documenting the deeds and land claims of elite families. The most famous of these manuscripts is the *Codex Zouche-Nuttall*, which chronicles in pictorial form the exploits of the eleventh century Mixtec king Eight Deer. All date from the last centuries before the arrival of Europeans. Although their emphasis is not on ritual or calendrics, images of origin myths and deities contribute to our knowledge of Mixtec cosmology.

All of these Central Mexican manuscripts include glyphs of names and dates in the 260-day calendar, rebus writing and symbols for geographic locales, but only the Maya painted books contain phonetic texts. Three examples escaped the friars' fires in the sixteenth century to appear in Europe: the *Dresden Codex*, the *Madrid Codex*, and the *Paris Codex*, named after their present-day locations. These books appear to have been painted shortly before the Conquest in Yucatan. A fourth book appeared in 1973, with claims that it had been discovered by looters in a dry cave in the Mexican state of Tabasco. Although it was rejected in some circles as a fraud at the time, subsequent radiocarbon tests indicate an age in the twelfth to thirteenth century CE, and the Venus tables it contains reflect Maya concepts that were not rediscovered until several years after the book's appearance. Contemporary consensus therefore holds it to be genuine. All of these Maya books contain tables of observations for predicting eclipses and the movements of celestial objects like Venus, almanacs for agriculture, and guides to ritual performance. Like the Borgia Group, they were once the property of indigenous priests.

Extra 5: Maya Myths in Historic Manuscripts

In the centuries following the Spanish Conquest, some indigenous myths, including much information on cosmology, were preserved by being recorded in Latin script by Native writers. In Yucatan, several versions survive of the *Book of Chilam Balam*, or Jaguar Priest. These variations of the text are titled after the town that was each one's origin. The most famous example of these was composed in the town of Chumayel. These contain oral historical traditions, astrology, ritual practices, and prophecies tied to the cycles of time in the Maya calendar. Some of this material appears to be of prehispanic origin and is a valuable source for understanding the world view of pre-Columbian Yucatan. However, it is also clear that events from colonial history and the Judeo-Christian tradition also figure in the *Books of Chilam Balam*, suggesting the need for caution in using their contents uncritically as a basis for understanding pre-Christian beliefs.

In the southern highlands of Guatemala, an epic poem of the Quiche Maya, the *Popol Vuh* or "book of the mat" (mats were a symbol of rulership in ancient Mesoamerica), was apparently written down in Latin script by a Spanish-schooled Maya shortly after the Spanish Conquest. No original of this early version has been preserved, but copies were transcribed into the mid-nineteenth century when they came to the attention of European scholars. Like the *Books of Chilam Balam*, the *Popol Vuh* seems to contain a considerable amount of prehispanic material, drawn both from oral tradition and screenfold manuscripts, though here, too, Catholicism and colonialism have made their mark upon the contents. The *Popol Vuh* is a history of the Quiche people incorporating a version of the Maya myth of the previous creations and destructions of the universe. Perhaps the most well-known section is the saga of the Hero Twins, Hunahpu, and Xbalanque, whose adventures intertwine with and set the stage for the last creation of the cosmos and man.

Recent studies in Maya epigraphy and iconography have demonstrated that aspects of the *Popol Vuh* – especially the Hero Twins epic – represent survivals of Maya myths dating back to the Classic period and probably earlier. The Hero Twins' legendary battles with the gods of the underworld recur in Classic Maya vase painting, and contribute to the trappings and ideology of Classic Maya kingship. The art historical and hieroglyphic material has in turn begun to permit the reconstruction of sections of the Classic version of the myth that did not survive to be incorporated in the colonial text. The identification of the father of the Hero Twins with the Maya maize god, his role in the creation of the world, and further details of the twins' defeat of the lords of death have emerged from Classic scenes and texts. The case of the *Popol Vuh* is one instance where post-Conquest materials have been fruitfully used to increase our understanding of pre-Columbian beliefs and symbols.

Extra 6: Olmec Cosmology

According to the theories of Joralemon (1996), based on his readings of Olmec iconography, the Olmec lived in a shamanic, multilevel mental universe akin to that of their Maya successors. In his view, the earth was pictured as a crocodilian Earth Dragon floating in a primordial sea. Mountains were its scutes, and vegetation sprouted from its back. Mountains may have been viewed as containing water as in later myths – certainly archaeology shows that the Olmec venerated mountains and springs. The sky was represented by a Bird Monster, and the ocean under the earth by the shark-like Fish Monster. As in Maya belief, this watery underworld was the home of ancestral spirits. According to Joralemon and other scholars like Reilly (1996), carvings of rulers seated in jaguar or serpent mouths are shaman-kings accessing portals to the underworld (Reilly) or the upper world (according to Karl Taube) through trance and ritual. The site of La Venta is now interpreted, along Maya lines, as a cosmogonic center, recreating the creation and structure of the cosmos through its architecture, buried offerings, and associated rituals. A stone mosaic intentionally

buried there has been read as an image of a jaguar, associated with the underworld via later Aztec and Maya myths; or as the saurian earth monster on the surface of the sea. Serpentine (greenstone) pavements from the same center have been interpreted as representations of the blue-green watery underworld itself. A massive pyramid, forerunner of later temple platforms throughout Mesoamerica, is equated with the primeval "Snake Mountain" which emerged from watery chaos at the creation of the world in later cosmogonies. Schele (1996) has interpreted Olmec art as reflecting belief in a world tree, the bridge between levels of the cosmos, equated as among the Maya with the person of the ruler. These interpretations, which seek to demonstrate continuity between Olmec and later cosmologies, are widely accepted, but not without critics who call assumptions of such continuity in beliefs over several millennia into question (Fig. 13).

Cosmology in Mesoamerica, Fig. 13 This inscribed greenstone celt from Rio Pesquero, Mexico, depicts an Olmec ruler symbolically equated with the axis mundi. His legs form the head of a serpent, and he holds another in his arms. The four-stylized corn plants represent the four directions. The ruler occupies the center, representing the mediating vertical axis of the universe which, like the king himself in his role as shaman, provides humans access to the supernatural worlds above and below the earth. This interpretation is by Linda Schele and F. Kent Reilly and is based in part on later Maya iconography (Middle Formative, ca. 900–400 BCE) (Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan))

Extra 7: The Maya Hero Twins

The myth of the Hero Twins Hunahpu and Xbalanque from the *Popol Vuh* is intertwined with the Maya creation myth. Its action is set during the transition between the end of the third creation and the inception of the fourth. Recent discoveries from epigraphy and art history reveal that the Classic version of this myth was even more explicitly tied to the story of the making of the fourth world.

The saga begins with a first set of brothers, Hun Hunahpu and Seven Hunahpu. During the Classic period, Hun Hunahpu was identified as the Maize God, and his death and rebirth in the narrative were associated with the cyclical growth of corn. This first pair were avid players of the traditional Mesoamerican rubber ball game, known in the archaeological record from Olmec times, played by the Aztec and Maya at the time of European contact, and still practiced today in parts of rural Western Mexico. Unfortunately, the noise created by the brothers' favorite pastime irritated the ruling gods of Xibalba, who summoned them to the underworld and challenged them to a ball game where the stakes were life or death. Because of the supernatural powers and trickery of the lords of Xibalba, Hun Hunahpu and his brother were rapidly defeated and executed. Their bodies were buried but Hun Hunahpu's head was hung up on a tree for display. As befitting a maize god, its presence made the formerly barren tree sprout an abundance of

fruit, identified with the calabash in the *Popol Vuh*, but apparently with cacao (chocolate) in some Classic Maya vase paintings.

One of the daughters of a lord of the underworld, Blood Moon, visited the tree out of curiosity at its sudden fertility. The skull of Hun Hunahpu hanging there spit into her palm, magically impregnating her. When her father learned of her pregnancy, he attempted to have her murdered, but she fled Xibalba to the middle world where she gave birth to Hunahpu and Xbalanque.

As youths, these twin boys distinguished themselves by a number of exploits. They defeated the bird monster Seven Macaw, who falsely proclaimed himself to be the sun. This usurper seems to have been equated in the Classic period with Mut-Itzamna, the Celestial Bird shown perched atop the world tree. The vanquishing of this false sun seems to coincide with the destruction of the last creation. The twins also conquered Seven Macaw's son, the crocodilian Zipacna.

Eventually Hunahpu and Xbalanque discovered the ball game equipment of their father and took up the sport with great energy. Their noise eventually also reached the Lords of Xibalba, who summoned them to a challenge like that which their father and uncle had failed to master. Unlike the first brothers, the Hero Twins rose to the occasion, outwitting the ordeals and tricks of the gods of the underworld with clever strategies and magical powers of their own. In the last and most spectacular of these supernatural feats, the Hero Twins followed the advice of a diviner and submitted to execution. Their bodies were burned and their ashes cast into the waters of Xibalba. The rulers of the underworld believed they had defeated these troublemakers as decidedly as they had beaten their father.

But Hunahpu and Xbalanque were reborn, appearing first as catfish and then disguised as itinerant magicians. They performed a magic trick in which they killed each other and then magically restored the other to life. Hearing of this spectacle, the lords of Xibalba were intrigued and summon the performers to demonstrate this wonder. Having seen this miraculous resurrection, the underworld gods are so enthusiastic that they demand to be used as volunteers for the trick. Predictably, the twins kill the lords of death as requested, but do not bring them back to life.

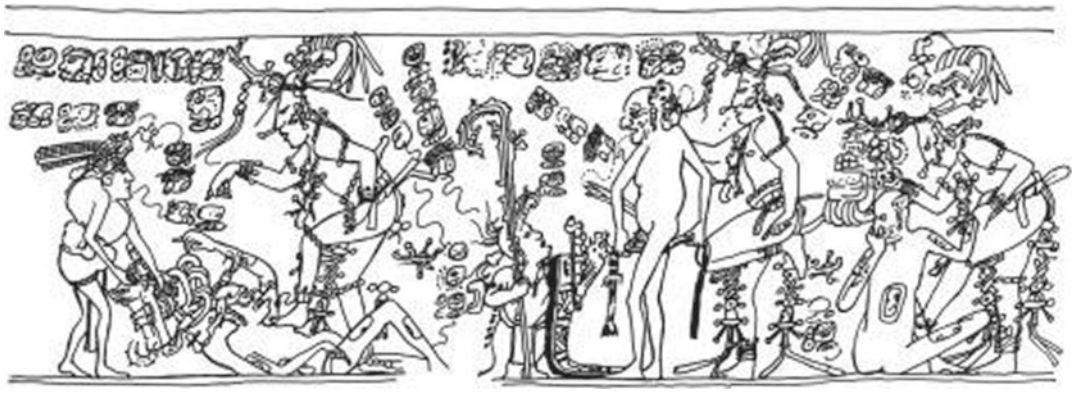
In the *Popol Vuh*, the twins attempt to raise their father and uncle from death, but are only partially successful, and cannot bring them back to the land of the living. The iconographic and inscriptional evidence from the Classic period provides an alternative ending. After defeating the lords of death, apparently with the connivance of the moon goddess and her rabbit, they succeed in resurrecting the Maize God, who is shown in several painted scenes as emerging from the body of a turtle representing the earth. The Maize God then acts as the demiurge of the most recent creation, separating earth from sky, raising the world tree, setting up three hearthstones (the traditional number in Maya houses) at the center of the universe, and erecting the vault of the heavens. In the Classic scenes and texts, the chief of the underworld gods is God L, an elderly deity associated with wealth and the profession of merchant. He appears not to have been sacrificed but humiliated and forced to pay tribute to the gods of the sky (Figs. 14 and 15).

The Hero Twins have been equated with the sun and moon, and the first brothers with Venus in its twin guises as Morning Star and Evening Star. In both versions of the myth, the victory of the Hero Twins limits the power of death in the world and points the way toward the hope of rebirth. Like the first brothers, the Maya elite were believed to descend to the underworld after death, but they hoped to be reborn as were both the Hero Twins and the Maize God, and to ascend triumphantly to the celestial world like the latter following his resurrection. Like the Christian myth in Europe, the story of the Hero Twins was the template for tomb art and funeral practices among the kings of the Maya, a model for their anticipated conquest of death.

Extra 8: A Nahua Cosmogram

The Codex Fejevary-Mayer is a painted manuscript belonging to the Borgia Group,

Cosmology in Mesoamerica, Fig. 14 Resurrection of the Maize God. This scene from a Classic Maya (600–900 CE) painted ceramic vessel shows the resurrection of the Maize God, pictured emerging from a cleft in the carapace of a turtle representing the earth. He is attended by his sons, the Hero Twins. The skull at the base of the cleft represents the head of the Maize God, decapitated following his defeat by the rulers of Xibalba. As corn sprouts from seeds, so human bones were viewed by the Maya as the seeds of eventual rebirth in the afterlife, following the pattern set by the Maize God's story (Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan))



Cosmology in Mesoamerica, Fig. 15 This scene, painted in black line on a white background on a ceramic vessel of the Late Classic period, illustrates a section of the Classic version of the myth of the Hero Twins not found in the later *Popol Vuh*. Following his resurrection by the Twins, their father, the Maize God, is depicted triumphant over God L, chief of the Lords of the underworld. On the *left*, the Maize God is trampling his former persecutor, while in the scenes at *center* and right, the Lord of Death is stripped of his regalia by the victorious Maize God. The dwarf accompanying the Maize God represents the undeveloped or stunted ears of corn frequently found attached to complete examples (Drawing by Linda Schele, copyright David Schele, reproduced courtesy of FAMSI (text by Keith Jordan))

manufactured probably in the Mexican states of Puebla and Tlaxcala in the century preceding the Spanish Conquest of 1521. The first image in this amazing pictorial document is a symbolic map of the cosmos organized around the four cardinal directions, complete with their associated divinities. This diagram, frequently reproduced in surveys of Mesoamerican art and religion, is a remarkable window onto the world view of the Nahuatl-speaking peoples of Central Mexico in the Late Postclassic period.

At the center of the diagram is the black world axis connecting the vertical layers of universe, represented by the fire god Xiuhtecuhtli. This deity spanned the three realms, and was thus equated with the axis mundi, as was his implement, the fire-drill. Streams of blood flow toward him from the four cardinal directions, representing the human sacrifices to sustain the gods. Each direction has its own associated tree, the pillars of the sky. As in most Mesoamerican maps and cosmograms, East is on top, with its patron deities Itzli (a personified sacrificial knife) and Tonatiuh, the sun god, its colors appropriately red and yellow. To the left is the North, ruled by Tepeyollotl, an aspect of the royal god Tezcatlipoca, and Tlaloc, the rain deity. North for the Nahuatl-speaking peoples was the direction where the difficult journey of souls to the afterlife began. Fittingly, its color is black. At the bottom is West, where the earth monster Tlaltecuhtli swallows the sun at sunset. The patron gods shown here are Chalchiutlicue, goddess of ground water, and Tlazelteotl, "eater of filth," a goddess of sin and confession. Its color is white. To the right is South, associated with blue and green. Here a cocoa tree accompanies the ruling deities of this direction, Mictlantecuhtli, the skeletal god of death and the underworld, and Centeotl, the goddess of mature corn. Between the arms of this cosmic cross are the four intercardinal directions: summer solstice sunrise, upper left; winter solstice sunrise, upper right; summer solstice sunset, lower left; and winter solstice sunset, lower right. The eight-lobed band around the world trees represents the 260-day ritual calendar. Like the other books of the Borgia Group, Fejevary-Meyer contains information for divining the future of individuals based on their birth date in the 260-day cycle. It probably belonged to a priest or oracle.

See Also

- ► Astronomy in Mesoamerica
- ► Calendars in Mesoamerica
- ► Eclipses in the Americas

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Cosmology of the African San People

Sven Ouzman

Using words to capture and convey our beliefs and experiences may seem precise and comprehensive, but such omniscience is illusory (Mitchell, 1994). It may, however, be possible to fragment the totalising influence of words and concepts like "cosmology" – knowledge of the world – by using historically specific texts, images, sounds and sensoria to promote epistemological diversity. This approach works well

Cosmology of the African San People, Fig. 1 Bushman group, colonial South Africa, 1884 (From Bleek and Lloyd 1911, p. 99)

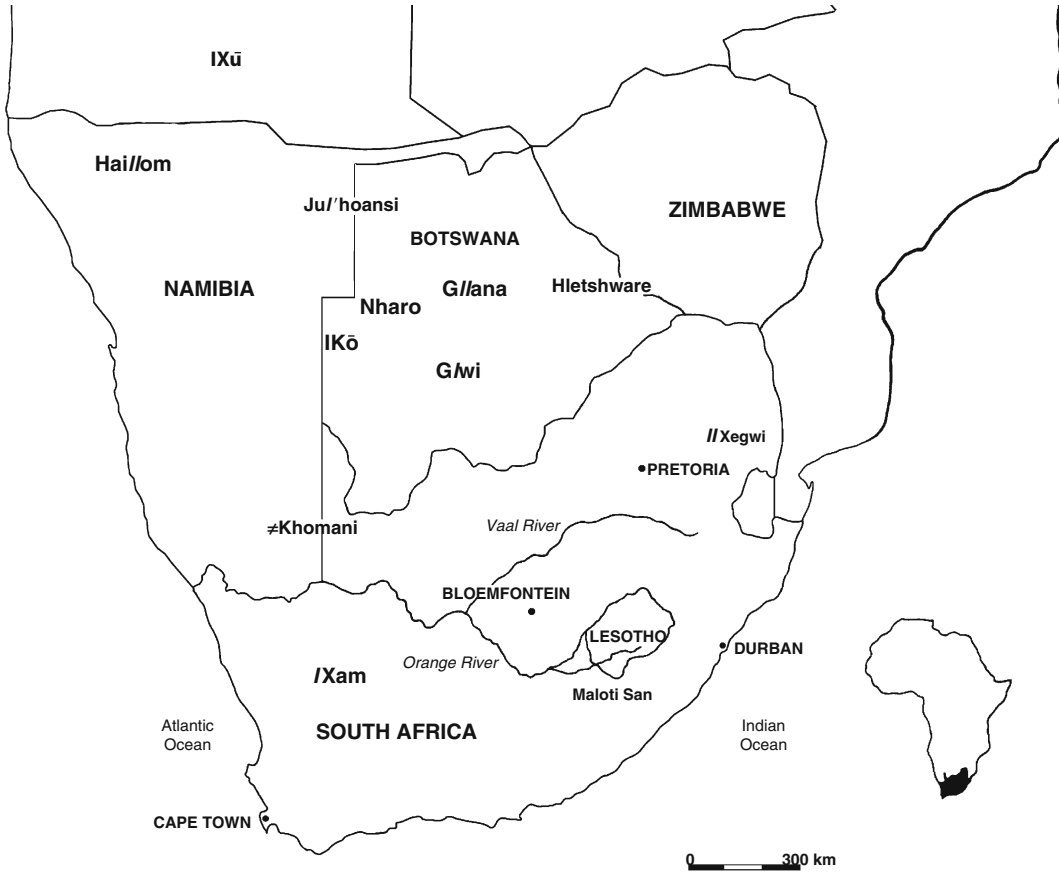
within a culture. I can, for example, distinguish between Southern Baptist and Greek Orthodox as two heterodox forms of Christianity. But what about other people, in other places, at other times? The people on whose behalf we interlocute – in this case the San or Bushmen of southern Africa (Extra 1) – have histories marked by imperialism, colonialism, missionisation and Apartheid (Fig. 1). How then do we know when our information about these people draws on their remembrances of original traditions or when it embodies recent histories of violence? Despite ethnography's ethical problems (Clifford & Marcus, 1986), we can use multiple strands of evidence to produce working knowledge that tacks between absolutism and hyper-relativism (Benhabib & Fraser, 2004).

A First People

The San of southern Africa (Fig. 2; Hyperlink 1) are the most studied people on earth because of their perceived uniqueness as models of original humanity. Such study has not always been accurate. In 1719 the German astronomer Peter Kolb published the statement that Hottentots worshipped the praying mantis (*Mantis religiosa*), generating the Mantis God myth (Marshall, 1999, pp. 242–245). In fact, this insect worship was San genuflecting to the powerful trickster, Kaggen, in one of his many corporeal forms (Barnard, 1992, pp. 84–85). Even today myths endure. San contextual egalitarianism, shamanic healing and environmental stewardship are often represented as timeless and apolitical, ossifying the dynamic and idiosyncratic flow of San life in which individual action and cosmological constants combine to create a flexible matrix for being in the world (Extra 2). San groups present and past do, however, show remarkable congruence in "territorial organisation, gender relations, kinship, ritual, and cosmology" (Barnard, p. 3). For example, colonial ethnographies suggest a common origin realm inhabited by "People of the Early Race" (Bleek & Lloyd, 1911, pp. 55–57, pp. 175–199), who both created the cosmological order and delight in transgressing its boundaries. This primal time relies less on personnel, location or temporality than on the relationships between these components (Katz, Biesele, & St Denis, 1997, pp. 47–62). What we comprehend as separate Spirit and Ordinary worlds constantly intersect.

A Connective Cosmos

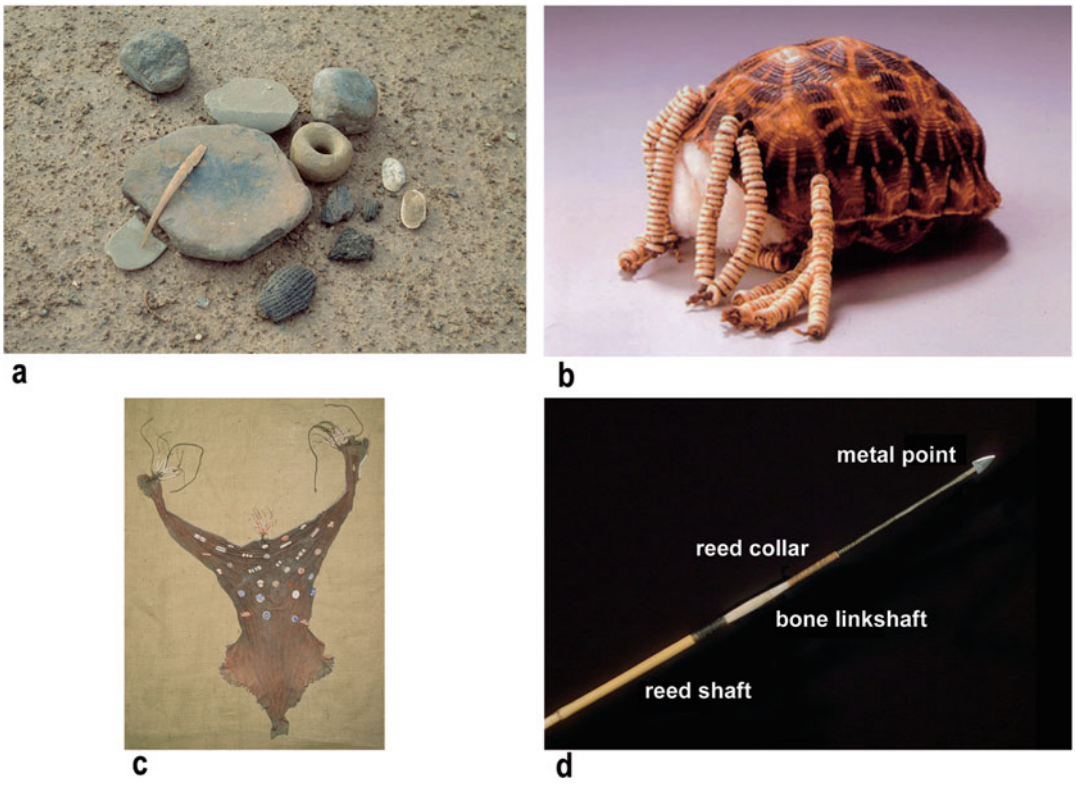
The Ordinary World has nodal topography studded with campsites, hunting grounds and



Cosmology of the African San People, Fig. 2 Distribution of San language groups

what Ju/'hoansi call *n!oresi* – bundles of relationships and obligations between animals, beings, people, places, plants and things (Katz et al., 1997, pp. 16, 50). Material traces of these relationships date back millennia, appearing as artefacts archaeologists classify on a continuum between functional and symbolic. Thus, artisanal artifacts such as stone tools and bone points grade into non-utilitarian items like ostrich eggshell beads and decorations, which intensify into symbolic crystals and rock art (Figs. 3 and 4). Some say functionality is easier to prove than symbolism. Yet our best evidence of San life is symbolic rock art present at over 30,000 sites (Ouzman, 1998; Extra 3). What we call images were for San actual apocalypse dogs, Beings, cynosuric animals, rain-animals, supernatural potency and part-human therianthropes emergent from an inner Spirit World behind the rock face.

Other connexions to the Spirit World, which exists in multiple locations above and below the Ordinary World, are via water, striking landscape features, and events like death and dancing. These do not permit universal access because the Spirit World is dangerous and inversive. It requires great skill to negotiate its pathways, cul-de-sacs, and denizens like the Spirits of the Dead. Two great but capricious gods – whom the G/wi call *N!eri* (creator) and//*Gauwa* (trickster) – have a fearsome entourage of wives, carnivores and spirits (Guenther, 1999, pp. 61–64). Consequently, the task of traversing worlds is left to shamans – skilled negotiators of boundaries who make sense of the seemingly impossible such as being neither and both male and female (Atkinson, 1992, p. 319). This skill is superhuman and requires what Ju/'hoansi call *n/om* – a supernatural potency vested by



Cosmology of the African San People, Fig. 3 San material culture. (**a**) Bored stone, bone scraper, freshwater mussel shells, grindstone, lithics, pottery. (**b**) Medicine container. Hearst Museum, University of California Berkeley, California. (**c**) Decorated leather woman's apron. (**d**) *Arrow*

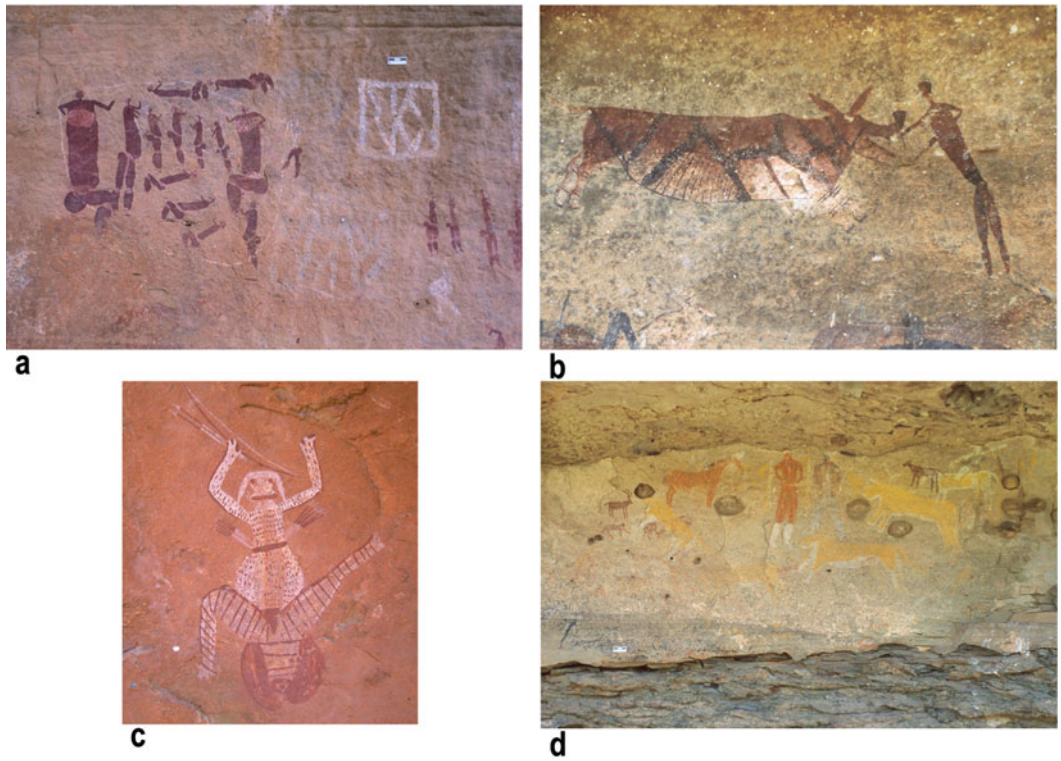
God in certain interconnected receptacles such as comets, honey, lightning, large animals, plants, rain, shamans or sun (Marshall, 1999, 20, pp. 49–62, p. 218).

The spirit is in the air. When you dance it comes down to you. When it gets into you, you can see it as a string of light. The light carries you in the dance. It can take you to another person who needs healing or it can carry you to another village in the sky. The light is *num* [*n*/*om*]. It doesn't have another name than *num*. Xixae Dxao (Keeney, 2003, p. 41).

But potency, like the gods, is complementary – a foundational feature of San cosmologies. Small amounts of potency aid apotropaism astral travel, healing, and rainmaking, but high concentrations can kill. Controlling potency and passage to the Spirit World requires everyone's labour (Katz, 1982, pp. 34–57). Nowhere is this complementarity better exemplified than in the Medicine Dance – perhaps humanity's oldest surviving ritual (Hyperlink 2). The atmosphere of the Dance is social and electric. People clap, dance, sing and talk to create a spiritually charged and socially cohesive atmosphere that launches shamans to the Spirit World.

It is endlessly varied by disciplined improvisation, within the bounds of repeated musical phrases. When the awesome sound of the men's rattles is added to the singing and sharply clapped cadences, a music of truly unearthly beauty is produced. This music is one of the basic vehicles of transcendence, enabling curers to achieve the altered state of consciousness called trance (Biesele, 1984, pp. 165–166).

> In trance, with the support of the women in the community, who sing and clap, a master of trance works himself into a state where he transcends himself and enters the realm of the supernatural



Cosmology of the African San People, Fig. 4 San rock art. (**a**) Medicine dance, (**b**) Rain-animal, (**c**) Therianthrope and (**d**) Colonists

> where the ghosts of dead ancestors live. Here he struggles with the ghosts. The struggle is intense both emotionally and physically. He is overcome with pain and fear, afraid that he will lose himself in the realm of the supernatural and not return. (Wiessner & Larson, 1979, p. 25)

The physical and spiritual labour of females, males, children, movement, sound, spirits and potency is thus not equal but harmonises. Shamans are pre-eminent but they serve a community. The Medicine Dance is an enduring *genius loci* still performed in Angola, Botswana and Namibia where it attracts non-San like Damara, Herero and Tswana for healing and community. The Dance incorporates elements of ecstatic Christianity and political resistance, whereby shiny European goods are eschewed and shamans act as agents of social change by voicing concerns about alcoholism, marginalisation and so forth (Guenther, 1999, pp. 195–196).

San Science: Past, Present and Future

San cosmology is thus not narrowly spiritual but entails "an all-encompassing world-view, the influences of which extend into every sphere of their existence" (Yates & Manhire, 1991, p. 3). An especially complete synthesis of gender, science, religion and technology is !Kõ and //Gana arrow poison (Heinz, 1978, p. 151; Hyperlink 3; Neuwinger, 2004). The paralysing toxin comes from the haemolymph of *Diamphidia simplex* beetle larvae and cocoons, but not the adult beetle (Fig. 5; Hyperlink 4). These larvae live up to 1 m below the ground near a host tree, the sandy corkwood (*Commiphora angolensis*). Six to ten larvae are sufficient for one arrow's toxin, which is applied by man-the-hunter (Hyperlink 5). San arrows are tripartite constructions designed so that the impetus of the linkshaft breaks the reed collar, causing the shaft which the animal could otherwise dislodge from its body to fall away,

Cosmology of the African San People, Fig. 5 *Diamphidia* beetle cocoons and larvae used for arrow poison (From Neuwinger, 2004)

leaving just the arrow point behind to deliver the toxin (Fig. 3d). But men are ignorant of the toxic larvae's location until women, more attuned to subterranean signs (Hyperlink 6), tell them where to look. This female-male, nature-science relationship is spiritually triangulated through the great God ≠ Gao N!a who "taught them how to find it and how to put it on their arrows so that they would have meat" (Marshall, 1999. p. 32).

Lest San be characterised as waning guardians of an ancient spirituality, it is useful to examine complementarities between San and Western worlds. Sometimes this juxtaposition is conflictual. Pfizer Pharmaceuticals were sued for bio-pirating ≠Khomani intellectual property of the appetite suppressing properties of the *Hoodia gordonia* plant, now marketed as a slimming product (Wynberg, 2004). In more fulsome spirit, the Cybertracker project pairs renowned San tracking skills with Global Positioning System (GPS) technology to aid game management and counter poaching (Hawthorne, 1999; www.cybertracker.co.za). San trackers, often text-illiterate but masters at reading sign, note spoor by selecting species-specific keypad icons. The GPS registers this input, capturing data like the location, movement, number and health of animals, which is transmitted to a central database. This hybrid approach is more effective than either San or Western science. Indeed, Western science may originate out of the art of tracking:

> To interpret tracks and signs trackers must project themselves into the position of the animal in order to create a hypothetical explanation of what the animal was doing. Tracking is not strictly speaking empirical, since it also involves the

> tracker's imagination. Generally speaking, one may argue that science is not only a product of objective observation of the world through sense perception. It is also a product of the human imagination. (Liebenberg, 1990, p. v)

More than science, San tracking is a deeply spiritual activity necessary for the renewal of life. "Tracking is like dancing. This is the Great Dance. You are talking to God when you are doing these things" (Hyperlink 7). However, while San cosmological complementarity works well in Habermasian ideal speech situations (Habermas (1929-) sets out five conditions for his ideal speech situation (a) Every subject with the competence to speak and act is allowed to take part in a discourse; (b) Everyone is allowed to question any assertion whatever; (c) Everyone is allowed to introduce any assertion whatever into the discourse; (d) Everyone is allowed to express his attitudes, desires and needs (e) No speaker may be prevented, by internal or external coercion, from exercising his rights as laid down in (a) and (b). (*Diskursethik*: 86). These conditions make possible free discourse and pure communicative action), these examples of accord should not mask the devastation of acculturation, cultural property theft, forced removals and genocide experienced by many San. Celebrating only the positive can veer dangerously close to liberal social contracts and commons that are open to unpunishable abuse (Hardin, 1968). Mindful of this, San have reformulated their egalitarian ethos to uplift themselves and to educate well-intentioned and wilful outsiders (WIMSA, 2003; www.san.org.za). The long and ongoing tradition of San cosmology is not something conservative and ancient, it is a fund of beliefs, places, objects, skills and stories that allow people to innovate and to impact the modern world.

Extra 1: The Name Game: San or Bushman?

Ethnonomy – the process by which people name themselves, are named by others, and the politics that determine which names stick – is critically important to people's sense of self. Both San – a Nama word meaning "vagabond" – and Bushman – an anglicisation of the Dutch *bosjemans* – are exonyms. Today's approximately 100,000 San who live in Angola, Botswana, South Africa and Zambia have group-specific autonyms like/Gwi, Ju/'hoansi, and !Kõ, which translate as people, real people or red people, but that do not apply beyond the group – even to other San (Traill, 1995; http://en.wikipedia.org/wiki/Khoisan_languages). The corporate term Khoisan was coined by Leonhard Schultze in 1928 (Barnard, 1992, p. 7) and conflates the overlapping but distinct histories of Khoekhoe herders like the Nama, with San. During Apartheid, Bushman and *Boesman* were deeply offensive, but today these words are being reclaimed as a form of resistance (Gordon, 1992, pp. 6–7). Where possible, group specific names should be used. Elsewise either San or Bushman are acceptable, if used respectfully.

Extra 2: San and New Ageism

Thanks to films like Jamie Uys' *The Gods Must be Crazy*, books like Laurens van der Post's *The Lost World of the Kalahari*, and high profile academic research, San are viewed as a distillate of pure humanity – noble savages. Such stereotyping, while well intentioned and having some basis, leads to social and political marginalistion. Nowhere is this more apparent than in the New Age movement's appropriation of San shamanism and rock art (Sullivan, 1995) and archaeology in general (Morris, 2005). Modern primitives' urge to leave offerings at archaeological sites, to mimic ceremonies and dress, and continued idealistic portrayal of San cosmology causes communities great distress (Katz et al., 1997). New Ageism is a very partial practice that selectively ignores modern circumstances like the syncretic adoption of Christianity and very real social problems such as alcoholism, domestic violence and persecution and how San succeed and fail to deal with these.

Extra 3: The Meaning of San Rock Art

In 1945 the French prehistorian Abbé Henri Breuil sent word to South African Prime Minister Jan Smuts of "a portrait of a charming girl who has been waiting for us on a rock in the Brandberg range for perhaps three thousand years." Breuil was describing what he thought to be a Phoenician White Lady painted on the rocks of Namibia's Brandberg (Breuil, 1955; www.namibia-1on1.com/Namibia-Northern/White-Lady-Of-Brandberg.html). Breuil's inability to acknowledge indigenous authorship of southern African rock art was influenced by the Eurocentric Great Chain of Being (Lovejoy, 1936). Hierarchically ordering the world between God atop and rocks below; white humans were placed nearer God while San, Bantu speakers and Khoekhoen were placed near and even under rocks. Art produced by these lower races was believed either simply to record daily life or to spring from an innate native ability to make art. Appreciation of San rock art's symbolic and spiritual meanings lay dormant until half-forgotten nineteenth and twentieth century ethnographies (www.lloydbleekcollection.uct.ac.za) revolutionized southern African rock art research (Lewis-Williams & Pearce, 2004; http://rockart.wits.ac.za). Today we know that most southern Africans made some form of rock art. Whether shamanistic San statements, group-specific Khoekhoen engravings and paintings, initiation and political resistance arts of Bantu speakers, or Depression-era marks of white work gangs, the landscape bears a multitude of marks – some of which have yet to be understood.

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Cotton in India

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The Indian subcontinent is one of the world's largest producers of cotton and cotton textiles. From a long time past, cotton and cotton textiles were major articles of trade. Due to the exposure to the world economy, cotton farming and textile production were shaped by a variety of external influences.

A key moment of transition in this history was the establishment of the British East India Company as a political power in the late eighteenth century. The Company was already a major buyer of cotton textiles for export to Europe. Later, as it gained territorial control, it tried to export raw cotton from India to the mills of Manchester. In the course of European interest in these Indian products, a great deal of data on Indian cotton and textile technology was collected. The knowledge revealed that while cotton was cheap in India, the yield of the lands that produced cotton was small. Despite this drawback, the availability of a wide range of natural dyeing materials and highly developed craft skills had made possible the largest and commercially most successful cotton textile industry of the premodern world.

There were many changes in cotton and cotton textiles in the last two centuries, but two features proved persistent. First, while cotton was extensively grown, productivity remained relatively low, and production was exposed to a variety of risks. Improvements in conditions of production have proved either difficult or controversial. Second, cotton textiles have done well in domestic and world markets, despite temporary setbacks in the early nineteenth century and the mid-twentieth. This entry will present a long-range survey of the products with particular reference to these long-term features.

Cotton Cultivation

Cotton is an indigenous crop in India, and it is grown in several regions, of which the most important ones before the nineteenth century were coastal Gujarat, Khandesh, and eastern Rajasthan in western India, Bengal in the east, Narmada Valley and Malwa in central India, and Rayalaseema and Coimbatore in the south. Before the Industrial Revolution and before the railways connected these regions with the major ports (c. 1870), cotton cultivation, cotton spinning, and sometimes cotton weaving on handlooms developed side by side in these zones. For example, in Bengal, cotton cultivation expanded because of the demand for certain varieties in the textile industry (Roy, 2012).

Descriptions of the Arabian Sea trade before 1500 CE recorded a trade in Indian cotton. Little is known as to how large or how systematic the trade was. Very likely, cotton trade did not involve a specialized trading system yet. This was to change in the seventeenth and eighteenth centuries under the impetus of Indo-European trade in cotton textiles. The expansion of textile production for export in Gujarat, Coromandel, and Bengal led to the growth of cotton production and trade in several regions.

While overland trade expanded, a small quantity of Indian cotton reached Britain in the early 1780s via Flanders and Denmark. In 1788, the Company placed an order for 250 tons of Indian cotton and placed its Bombay office in charge of implementing it. Bombay, however, found it difficult to divert the trade toward the Company ports. A large part of Gujarat cotton still went to Bengal overland, and the prices offered by the Europeans did not succeed in diverting this flow toward export trade.

The Napoleonic wars made trade between Britain and the United States uncertain and increased the importance of Asia for British manufacturers. It was becoming clear to the officials engaged in procuring Indian cotton that the demand in Manchester had grown too fast for the government alone to cope. Two Scottish firms, Forbes and Co. and Bruce, Fawcett, and Co., were hired to procure cotton for the Company. At the same time, Indian merchants began to export cotton to China. The export helped Britain, which consumed a great quantity of Chinese tea, balance its accounts.

Securing a future for the trade demanded attention to two obstacles – quality of ginning and the poor yield of indigenous cotton varieties. There was no one method of ginning and cleaning cotton practiced in India. The best methods were exceedingly labor intensive. For example, in the villages of western India, women rolled the seeded cotton with their feet upon an iron roller until the seeds were separated from the fiber. This process did produce very clean cotton, but at a glacial speed. Trade volume was growing too fast for these manual systems to be adequate. The cotton that came to the ports for loading, therefore, was generally of poor quality. A further difficulty with Indian cotton was the small lots usually traded, in turn, an effect of poor yield. The indigenous plant was a short bush that produced about half or even less than the American varieties on average.

The government's solution to the supply problem was enlistment of the support of amateur botanists. In the early 1840s a government experimental farm was started in Coimbatore under Robert Wight (1796–1872), a surgeon in the Company's service. His project lasted longer (12 years) than other similar ones, but, like these others, was in the end thought to be a failure. The other arm of policy was encouragement to private plantations. Between 1835 and 1850, several attempts to grow American cotton on Indian soil by American and European planters received the Company's approval. These projects did not succeed because the new varieties proved unsuitable to Indian conditions and because contracts between planters and peasants were difficult to enforce. Nevertheless, the knowledge of the seeds diffused among the peasants and was moderately successful with one variety, the New Orleans.

The 1860s presented the peasants and merchants with an unprecedented trading

opportunity. During the American Civil War (1861–1865), Manchester mills were forced to find ways of using more Indian cotton, and the price of cotton in Bombay soared. From this time onward, Indian cotton was established as a major article of trade, supplying raw material first to Manchester, then to the domestic mills set up in Bombay, and in the twentieth century also to cotton mills in Japan. The area under cotton increased from six to ten million acres in 1870 to 25 million in 1936. Cotton export increased from 803 million lbs in 1868 to 1,560 million lbs in 1930. Part of this growth was an effect of general expansion of cropped area, but the share of cotton in cultivated area also increased during these years. By 1940, India was the second largest cotton producer in the world after the United States. Domestic mills used a little less than half of the crop; the bulk of the exports went to Japan and the United Kingdom.

In the fifty years after independence in 1947, growth of acreage more or less stagnated in the South Asian region. In 2010, the combined acreage of India and Pakistan was 29 million, the largest among cotton-growing regions of the world, but not significantly higher than the acreage of 1950. More impressive was an almost fourfold rise in yield per acre between 1868 and 2010. Much of the increase occurred after 1950; in fact the most growth occurred as recently as the 2000s, whereas in the colonial era, yield was more or less stagnant at approximately 100 lbs per acre. The dramatic change in the 2000s was partly a result of irrigation and partly a contribution of the transgenic cotton varieties. The quantum of benefits of these cultivars and to whom these benefit go are controversial issues (Herring and Rao, 2012), but the fact of a rise in yield is incontrovertible.

The revival of cotton production sustained a parallel revival of the textile industry in the region.

Cotton Textiles

Around 1750, India is believed to have supplied a quarter of the world's industrial output. Such a large quantity reflected India's share in cotton textile production in the world and the increasing usage of cotton in Britain. India was home to an ancient cotton textile industry. The output of the loom came in immense variety and embodied a range of decorative skills. On the Indian Ocean littoral, during the 250 years following the Portuguese mariner Vasco da Gama's discovery of the sea route between Europe and India (1497), cotton textiles procured by the European merchants in Gujarat, Bengal, and the Coromandel Coast had come to shape consumer preference in the West.

Between 1820 and 1870, India's prominence declined, as British machine-made yarn and cloth started trading widely. India's decline together with the rise of a cotton textile industry in Britain produced two unfinished debates. One of these asks how much the British success depended upon capital and knowledge gained from Indian trade (see Riello, 2013). And the other asks how badly the Indian economy was hurt due to the decline of its textile industry. In the early twentieth century, nationalist critics of the British Empire claimed that the fall of trade caused devastation and misery among textile artisans. The fall, in fact, was concentrated in spinning of yarn by hand. Weaving did not suffer as much and even expanded from the late nineteenth century. Indeed, production of cotton cloth in handlooms rose by 30 % between 1900 and 1939.

By 1900, a modern factory industry in cotton textiles had also developed. The development was concentrated in three cities, Bombay, Ahmedabad, and Calcutta, because the capital engaged in these factories came from trading and banking firms based in these cities. Many of them had made money in the cotton export trade of the early nineteenth century and had close links with both the British and the Chinese markets for cotton. That knowledge helped Bombay's mill owners procure machinery and foremen from Manchester and sell cotton yarn to the handloom weavers in China. Their already entrenched position in overland trade gave them a handle on cotton trade that many European capitalists lacked. The Indian textile mill industry, in this way, started soon after the British industry did, using indigenous cotton, cheap

labor, British know-how, and a long-standing mercantile heritage.

Early in the interwar period, India and Japan were among the largest textile-producing countries, thanks to a significant wage advantage they shared over their Atlantic rivals. But between them competition was getting keener. Japan surpassed India in the Chinese market for yarn, and in the 1920s, it started selling cloth in India. Contemporary analysis blamed the colonial exchange policy with its bias for a mildly overvalued rupee. Industry insiders pointed at differences in labor productivity, work ethic, and employment systems. The textile mill owners in Bombay, however, were gaining political strength, thanks to the support they gave to the nationalist movement, and they successfully wrested a measure of tariff protection.

It was a paradox, then, that the developmental state that came into being after independence in 1947 decided to burden the mills with taxes and draconian restrictions. The paradox reflects the diverse origins of economic nationalism. The nationalist leader M.K. Gandhi, for example, favored rural handicrafts as the symbol of village self-sufficiency. The first prime minister, Jawaharlal Nehru, and his economic advisers, on the other hand, were interested in heavy industries like steel and industrial machinery. Squeezed between these two ideals, the cotton textile industry in India failed to take advantage of the postwar revival of world consumption, the benefits of which were reaped first by Europe and later Japan.

Within India, the textile mills were becoming moribund. The range of their production was narrow, and therefore, their market was sluggish. With closed access to international know-how, the mills continued to decline and yielded space to small power-weaving factories called "power looms." The technological paradigm that came to rule the cotton textile industry in the 1980s was one that used old generic machines, produced unattractive cloth at low prices, and catered to a home market that was losing interest in homegrown cotton cloth. In 1991–1992, the trade regime liberalized. Export of textiles and import of equipment were again encouraged. Deregulation removed barriers to expansion and modernization. It was already too late for the textile mills. Instead, small-scale textile and clothing firms took advantage of the return to the world market.

In the present times, the textile and clothing industry of India, Pakistan, Bangladesh, and Sri Lanka form the most important manufacturing sector in the domestic economy. They are also very export oriented and almost entirely located in small-scale firms, though there is huge variation in capacity and size among these firms.

Conclusion

The overwhelming importance of cotton in South Asia owed to the region's natural advantage in cotton cultivation and accumulated knowledge of textile production. These strengths were tested in the nineteenth century when expanding demand for Indian cotton faced a geographical barrier and again in the twentieth century when an autarkic regime slowed learning and skill formation in textile production. These barriers were partially overcome by a combination of technological and political means at the turn of the twenty-first century.

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Cotton in Indonesia

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Since the early 1980s, Indonesia has become one of the world's biggest exporters of cotton textiles and garments. The expansion of textile

production was based on the processing of imported yarn and raw cotton, rather than domestically grown cotton. This development renewed interest in increasing the local production of raw cotton to reduce import dependence. During the next 25 years, the Ministry of Agriculture pursued various ways to expand the area under cotton and raise productivity, most recently in 2009, as part of a 5-year strategic plan that envisaged lifting domestic cotton production from less than 5,000–63,000 t in 2014, or 12 % of the expected raw cotton needs of Indonesia's textile industry. All signs are that this target will not be reached, as domestic production lingered at an annual average of 3,000 t during 2008–2012.

This outcome may not come as a surprise when looking back in time. Since the nineteenth century, public authorities in Indonesia have unsuccessfully tried to encourage raw cotton production for domestic consumption and export. Due to the country's location around the equator, Indonesian farm households produced raw cotton that sustained a local textile industry. In the course of the eighteenth century, the country imported increasing amounts of cotton cloth. Initially local traders and the Dutch East Indies Company (*Vereenigde Oost-Indische Compagnie*) arranged these imports mainly from India. During the nineteenth century, cloth imports came increasingly also from England and the Netherlands and since the early twentieth century also from Japan. Only the introduction of trade protection in the 1930s bolstered domestic cotton spinning and weaving for domestic consumption. This expanded since the 1950s, but still on the basis of imported yarn and raw cotton, as domestic cotton production remained relatively marginal.

A reason for growing dependence on imported cloth was that Indonesia was and continued to be a marginal producer of raw cotton. Various native cotton varieties were produced throughout Indonesia, particularly in Central and East Java (Demak, Pati, Jepara-Rembang, Madiun, and Madura), South Sumatra (Palembang), and Nusatenggara (Lombok and Flores). A maximum of 25,000–30,000 ha was harvested annually from the 1850s to the 1930s. However, the preferred varieties produced short-stapled and coarse fibers. These suited the very basic domestic spinning and weaving technologies, but the increasingly mechanized spinning and weaving machinery elsewhere in the world required the long-stapled, fine-fiber cotton varieties that were produced in India, Egypt, China, and the Americas.

The Dutch colonial government in Indonesia tried to encourage raw cotton production since the 1820s, as it was interested in promoting cotton exports, in part to help meet the growing demand for raw cotton by the budding textile industry in the Netherlands. Local and imported varieties were used in a long series of government-orchestrated tests aimed at introducing cotton production and/or improving the quality of the produced raw cotton, particularly in Palembang, but also several other areas such as Banyuwangi (East Java). But the results of all these government efforts were generally discouraging.

Private interests also tried to expand raw cotton production. For example, in 1843 J.L. van Toll used his experience with cotton growing in Surinam to establish a cotton plantation in Cirebon in Java. Although the cotton produced was of good quality, the venture was not commercially viable and ceased in 1847. In the late 1840s, the Netherlands Trading Company (*Nederlandsche Handel-Maatschappij*) supported tests in Palembang to explore possibilities for large-scale cotton production, but abandoned these plans. In 1861 an enthusiastic proponent of cotton production in Indonesia, J.J. van Limburg Brouwer, established the Netherlands Indies Cotton Company Ltd. (*NV Nederlandsch-Indische Katoen-Maatschappij*), which operated a cotton ginning and packing plant in Surabaya and sought to purchase locally grown cotton in nearby Demak and Grobogan. Despite high cotton prices due to the American Civil War, the venture failed to secure the required regular supplies of raw cotton from local growers and the company ceased operations in 1864. In 1905–1907, the Wijnkoopsbaai Exploration Company Ltd. (*NV Wijnkoopsbaai Exploratiemaatschappij*) distributed imported cotton seed free of charge among farmers in the

Pelabuan Ratu region in West Java, but it failed to encourage sufficient local production of raw cotton for purchase and processing. In 1916, the Moluccan Trade Partnership Ltd. (*NV Moluksche Handelsvennootschap*) established a plant in Palembang for the ginning of local raw cotton. It experienced irregular supplies and abandoned the venture in 1930. The Amsterdam-Sunda Company Ltd. (*NV Amsterdam-Soenda Compagnie*) was established in 1917 to produce and process cotton of a promising local variety in Flores. It ceased operations in 1924, when pests reduced yields and international cotton prices fell. In the 1930s, Dutch settlers and the Japanese South Seas Development Company (*Nanyo Kohatsu Kaisha*) tried to grow cotton commercially in New Guinea, but experienced pest problems within a few years. They also found that soil and climate were not always suitable and that yields were too low to make the ventures viable and ceased production in 1939.

Unsuitable local rainfall patterns and soil conditions as well as problems with several pests were key reasons why domestic raw cotton production in Indonesia remained limited. However, the main reasons why Indonesian farm households shunned cotton as a cash crop were the high risk of crop failures, because the plant requires high rainfall in the initial growing stages and then a very dry maturing season. Cotton also yielded low financial returns compared to other crops. Only when world prices were high did Indonesian farmers increase cotton production. In Java, they only did so as a second crop on irrigated fields following the main rice crop, but only in areas where other crops would yield even lower returns than cotton. Given the risk of crop failure (and the low financial yields), cotton-growing farm households did not put a lot of time and effort into weeding and pest control.

Hence, raw cotton was generally produced for local production of yarn and cloth for consumption by local rural households. The varieties that suited the local climate best yielded short, coarse cotton fibers and therefore coarse cloth. Some areas in Indonesia exported much of their raw cotton to China and Japan, where it was blended with other fibers and used in the textile industry. Very small quantities of ginned, superior raw cotton were exported to Europe. Although the share of ginned cotton increased during the 1900s, most of the exported raw cotton was ginned overseas. Given the uncertainty in the production and trade of Indonesia-grown cotton, much of the raw cotton trade was in the hands of small Chinese traders who purchased relatively small quantities from farmers for export. As most cotton was exported raw, the risk of contamination of the fibers by the oils from the seeds was high, and the quality of the exported cotton was on average low.

Estimates of domestic raw, seeded cotton production are rough, but they suggest that production was less than 5,000 t in the 1930s, rising quickly to 30,000 t in 1945, before declining to less than 1,000 t until the late 1970s. Production increased again since the early 1980s to a maximum of around 5,000 t. However, production fluctuated significantly from year to year, depending on crop failures and the prices of cotton and synthetic fiber substitutes. Throughout, farm households continued to be the main producers of cotton, and in the main cotton-producing regions, traders would purchase surplus cotton for export and/or processing into yarn. Nusatenggara and East Java continued to be among the main cotton-producing regions, but South Sulawesi replaced South Sumatra as the leading cotton-producing region.

The only significant expansion of domestic cotton production occurred during the Japanese occupation of Indonesia during 1942–1945, when the country was cut off from foreign supplies. In 1943, the Japanese authorities announced a plan to make Indonesia self-sufficient in cotton within 5 years. Using a degree of compulsion to persuade farmers, they succeeded in expanding the area under cotton in Java from 5,500 ha in 1940 to 33,000 ha in 1943 and 137,000 ha in 1945. However, crop failures and the unfamiliarity of many farmers with the crop resulted in poor yields. The drastic shortfall of cotton textiles had to be met with imports of yarn and cloth as soon as Indonesia resumed exports of other commodities in 1946.

In the 1950s and 1960s, Indonesia's imports of raw cotton, yarn, and cotton cloth increased steadily, although at times significant shortfalls in export earnings forced its government to impose limits on such imports. In that context, ambitions for the country to become self-sufficient in key commodities such as rice and cotton reemerged. In 1960, Indonesia's Eight-Year Development Plan echoed such intentions. It retained some realism by scheduling reductions of cotton imports on the basis of increasing supplies of rayon (cellulose fibers) produced from Indonesia's abundant forestry reserves, rather than only an expansion of cotton production. The FAO supported research into the feasibility of increasing cotton production in Indonesia around that time. But all plans came to little, as Indonesia's economy deteriorated in the early 1960s. Imports of raw cotton and yarn increased again as soon as Indonesia's economy recovered after 1966 and its oil boom started.

During the 1970s and 1980s, Indonesia's public resources for agricultural research and extension were concentrated on raising the production of staple foods, particularly rice, before they diversified to include non-food agricultural production to a greater degree. In the 1970s the agricultural extension service sought to increase cotton production in some areas that appeared suitable. Extension efforts focused on South Sulawesi, where during 1973–1977 state-owned General Company for Cotton Plantations in Indonesia (*PERUM Perkebunan Kapas Indonesia*) sought to foster cotton production among local farmers and purchase cotton for processing and marketing. It was unsuccessful for various reasons, including inadequate assessment of agroclimatic conditions; limitations on the amount of high-quality seed, fertilizer, and pesticides that the company could make available; and insufficient credit for farmers to purchase such inputs. In addition, the company did not have processing facilities in South Sulawesi to gin cotton. During 1978–1990 the Smallholder Cotton Intensification (*Intensifikasi Kapas Rakyat*) program was implemented in key cotton-growing regions, mainly by the Ministry of Agriculture, which coordinated the involvement of state-owned enterprises, regional extension officials, and local authorities. Buoyed by relatively high international cotton prices, in the early 1980s, the program succeeded in making South Sulawesi the largest cotton-producing region in Indonesia. But its results were mixed for reasons similar to the 1970s, particularly the variable supplies of superior seed and chemical inputs.

The availability of superior seed improved after 1983, when the Ministry of Agriculture started to support cotton-related research at what is now the Indonesian Sweetener and Fibre Crops Research Institute in Malang. The Institute has since released a range of hybrid Kanesia (*Kapas Nasional Indonesia*) cotton varieties. These new varieties are pest resistant and potentially high yielding and produce a better quality cotton fiber, and due to drought resistance, they may suit local growing conditions better. The institute supplies superior seed to private seed companies for the further multiplication and marketing of seed to farmers through local farmer groups. The institute also conducts demonstration farms and field schools, and its researchers meet with farm groups and local extension workers to monitor results and receive feedback.

This had some results in South Sulawesi, where cotton production increased during the 1990s. This was partly due to the impact of further government programs that improved the availability of seeds and inputs, as well as targeted credit to farmers, but it was also in line with high international cotton prices in 1994–1996. Several firms established processing facilities in the region and elsewhere for the ginning of cotton purchased from farmers, including *PT Nusa Farm* and *PT Kapuas Garuda Putih*. Nevertheless, production decreased again in the region after 2000, when the supply of inputs and credit was largely left to the private sector. As part of the change in policy, *PT Branita Sandhini*, the Indonesian subsidiary of multinational Monsanto, was given permission to distribute imported transgenic pest-resistant Bollgard cotton seeds. This experiment stirred public discussion, but eventually failed to catch on.

Expectations that private sector involvement in the distribution of seeds, inputs, and credit, as

well as the purchase and processing of raw cotton, would increase cotton production did not materialize during the 2000s, despite efforts by the Ministry of Agriculture to give new life to extension programs involving the private sector in 2007 (with a production target of 70,000 t in 2010) and in 2010 (with a target of 63,000 t in 2014). Since the early 2000s, the harvested area with cotton decreased to an average of around 10,000 ha during 2008–2012, despite the fact that international cotton prices skyrocketed in 2010–2011. Cotton yields in Indonesia remained on average around 0.3 t per hectare during 2008–2012, or just one-third of the world average. The main reasons for the reluctance of farmers to grow cotton appear to be the same as before the 1940s. Cotton production is generally still less profitable to farm households than the production of other crops, particularly rice. This is partly due to the low yields of the traditional local cotton varieties, which remain vulnerable to pests and crop diseases and tend to be grown on marginal land with unreliable water supply.

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Couscous

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Couscous is a semi-prepared foodstuff produced since ancient times. Couscous is known by different names in different countries. It is known as kuskus in Turkey, couscous in Morocco, maftoul in Jordan, moghrabieh in Lebanon, seksu in

Couscous, Fig. 1 Rubbing bulgur with egg whites

Couscous, Fig. 3 Pouring on bulgur of the egg milk mixture

Couscous, Fig. 2 Sprinkling on bulgur of flour and rolling bulgur

Couscous, Fig. 4 Sieving couscous

Berber, kusksi in Libya, keskesu in Tuareg, kouskousaki in Greece, and attiéké in West African (Anonymous, 2013a). In Turkey, wooden bowls (average 60 × 120 cm in sizes) are used for producing homemade couscous. When using 1 kg of coarse bulgur for couscous, 25 eggs (the amount of egg is variable), 3 kg of boiled and cooled milk, 35 g of salt, and 10 kg of wheat flour are the ideal amounts. First, a homogenous mixture is prepared with the eggs, milk, and salt. Four egg whites are not added to the mixture. Bulgur is rubbed with the four egg whites in the bowl (Fig. 1). Bulgur gets wet and swells. A handful of flour is sprinkled on the bulgur. Then, it is mixed right-left by hand and placed at the bottom of the bowl for 15–20 s (Fig. 2). Afterward, an average of 5 ml of egg-milk mixture is sprinkled on the bulgur using a dry bunch of corn husk. The amount of egg-milk mixture must be less when semolina and fine bulgur are used. After adding the egg-milk mixture, the bulgur is rolled for 15–20 s again (Fig. 3). Then, a handful of flour is sprinkled on the bulgur and the rolling process is applied again (Fig. 2). The bulgur starts to transform into couscous. When the couscous reaches the ideal size (approximately 3–4 mm), it is sieved in the wooden bowl (Fig. 4). Before it is sieved, it is sprinkled two consecutive times with the egg-milk mixture without flouring to be brighter and then rolled. Sieves, with holes of an ideal size for couscous and made from animal skins, stretching across a hoop, are used to separate couscous into different sizes. Couscous remaining on the sieve is laid on a sheet (Fig. 5)

Couscous, Fig. 5 Laying and drying couscous

Couscous, Fig. 6 Serving couscous in Turkey

at a location with airflow and shade and allowed to dry or dried in the form of baking. The process of flouring and sprinkling egg-milk mixture continues for small couscous passing through the sieve. Making couscous using 1 kg of bulgur takes approximately 3 h. Most people think that the product will not have the original natural scent and flavor after being baked in oven. Couscous is stored in cloth bags.

When the water begins to boil, couscous is added to it. Or couscous can be fried in oil and water is added. Also water can be added to hot oil, with the water boiling at the same time. Then the couscous is added. The cooking process takes about 20 min. Salt (according to taste) is added during cooking. Butter is added after fat-free cooking. After taking the water from the couscous, in other words, after cooking, the pots are covered first with a cloth and then with a pot lid. So the couscous is infused. While the couscous is around 3–4 mm in diameter before cooking, it is around 5–6 mm in diameter after cooking. It can be served plain (Fig. 6) or with sauce or cheese (Coskun, 2013).

In North Africa, couscous can be prepared with semolina of hard wheat (*Triticum durum*), although it can also be prepared with barley, millet, sorghum, or corn. Couscous is processed from fine and coarse grains of semolina (Clifford, 2004). Rolling done to aggregate the semolina is realized in a large wooden dish called *guessâa* (Fig. 7). Four different sieves named *dekkak*, *reffad*, *meâaoudi*, and *sekkat* are utilized in sieving or sizing operations and correspond, respectively, to 500, 1,000, 1,130, and 1,280 μm mesh opening. The procedure starts with a quantity of 500 g of coarse semolina (>500 μm) steam-precooked in a *keskes* (couscousiere) (Figs. 8 and 9, Anonymous, 2013b) for 8 min at 95 °C. Salted water and fine semolina (≤500 μm) are progressively added for rolling in the guessâa. A sizing operation with sekkat sieve (1,280 μm) is practiced before drying under shade and natural air convection (Benatallah et al., 2008). It is always steamed, never boiled (the tiny particles to the left in the photo) (Fig. 10). The two at the right are Levantine pearl couscous (Fig. 10). The small ones (about 0.14 in./3.5 mm), called *maftoul*, were made in Jordan. The larger ones (about 0.22 in./5.5 mm), called *moghrabieh*, were made in Lebanon. These forms are boiled or used in soups and stews like regular pasta rather than steamed (Anonymous, 2013a).

According to a cooking method applied in Morocco, couscous is washed in a large shallow pan with much water. Couscous is spread in a rimmed baking sheet or similar appliance and allowed to swell for 10 min. Stew or broth is added and allowed to boil at the bottom of the pot. The steamer pan is placed on top, sealed as necessary, and the couscous is poured in. The couscous is steamed for 20 min in a couscousiere and is dumped into a shallow pan. One teaspoon of salt and about 3/4 cup of water (for two cups of couscous) is sprinkled evenly over the couscous.

Couscous, Fig. 7 Rolling done to aggregate the semolina in "guessâa"

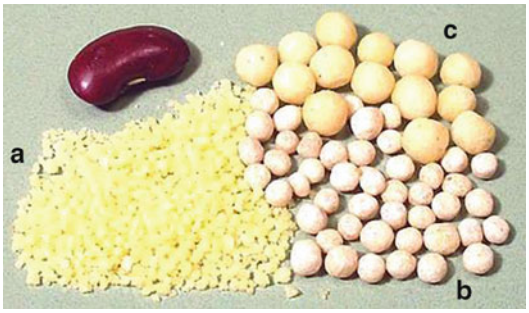
Couscous, Fig. 8 Couscousier

Couscous, Fig. 9 Couscousier

Then, the couscous is coated with olive oil by hand and must be allowed to rest for at least another 10 min. The couscous is mounded onto a serving plate, and a deep depression is made on top of the mound where some of the stew is put in there (Anonymous, 2013c).

Couscous, more affectionately known as seksu or sikuk, is the national dish of Morocco. While in most Moroccan families this rolled semolina cereal is prepared and eaten on Fridays, a few incorporate couscous into their diet at least a few times a week. Couscous is also a celebratory dish eaten at weddings, funerals, or the end of festivals or holidays like the 27th of September, an important date in Ramadan (Anonymous, 2012).

In Morocco, Algeria, and Tunisia, couscous is generally served with vegetables (carrots, potatoes, turnips, etc.) cooked in a spicy or mild broth or stew and with some meat (generally chicken, lamb, or mutton) (Fig. 11, Anonymous 2013d). In Morocco and Algeria, it is also served, sometimes at the end of a meal or just by itself, as a delicacy called *seffa* (Anonymous, 2013e). In Libya, it is mostly served with meat. Another way to eat couscous is as a dessert; it is prepared with dates, sesame, and pure honey and is locally referred to as *maghrood*. In Egypt, couscous is



Couscous, Fig. 10 (**a**) North african couscous (**b**) Israeli couscous (**c**) Lebanon couscous

Couscous, Fig. 11 Serving of couscous in Morocco

eaten more as a dessert. It is prepared with butter, sugar, cinnamon, raisins, and nuts and topped with cream (Anonymous).

The instant couscous that is sold in most Western supermarkets is pre-steamed and dried; the package directions usually include adding 1.5 measures of boiling water or stock and butter to each measure of couscous and covering tightly for 5 min (Anonymous, 2013e).

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Crop Domestication in the Amazon

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Domestication of landscapes and plant and animal populations is a behavioral trait of humans and has been since the Pleistocene (Rindos, 1984; Smith and Zeder, 2013; Tudge, 1999) It follows that the humans who first arrived in Amazonia – perhaps 20,000 years ago (Lahaye et al. 2013) – were not mere hunter-gathers, but were at least part-time domesticators and horticulturalists, contrary to standard stereotypes. The first archaeological evidence of plant population domestication in lowland South America appeared by 12,000 years ago in western Ecuador (Piperno & Stothert, 2003) and the domestication process must have started earlier to become visible then, since evolutionary processes, like domestication, have time lags between the

founder event and visibility in the archaeological record (Rindos, 1984).

Landscape domestication is a cultural process whereby human intervention in the landscape and manipulation of landscape components cause changes in landscape ecology and in the demographics of its plant and animal populations, resulting in a landscape more productive and congenial for humans (Clement, 1999a, 2014). Because it is a process, the intensity of intervention and manipulation vary through space and time along a continuum from pristine through promoted, managed, and cultivated to settlements and cities (Clement, 2014). Plant population domestication is a coevolutionary process in which human selection of the phenotypes of individual plants results in changes in the population's phenotypes and genotypes that make them more useful to humans and better adapted to human intervention in promoted, managed, or cultivated landscapes (Clement, 1999a). Because it is a process, the intensity of selection and plant response to selection vary through space and time along a continuum from wild through incipiently domesticated to semidomesticated to domesticated, although not all species used and selected by humans contain examples of all these categories. Species with domesticated populations are expected to contain examples of all of these, but some may currently be extinct and only identifiable in the archaeological record. An Amazonian example is manioc (*Manihot esculenta*, Euphorbiaceae), the most important energy staple domesticated in the region, with thousands of domesticated varieties, but in which no incipiently domesticated populations have been identified. Other species may contain only incipiently domesticated populations, even when the species is very important in subsistence, in which case landscape domestication may be more important than population domestication. Amazonian examples are the two major species of assai (*Euterpe oleracea* and *E. precatoria*, Palmae), the latter perhaps the most abundant palm in Amazonia and the former the most abundant palm in the floodplains of the Amazon River estuary (ter Steege, Pitman, Sabatier et al. 2013). Their abundance may be partially due to human promotion and management, as both contain incipiently domesticated populations (Clement, 1999a).

A crop is "a cultivated plant that is grown as food, especially a grain, fruit, or vegetable" (http://www.oxforddictionaries.com). This definition affirms that the plant is grown in a cultivated landscape, and this implies that it is domesticated, although wild plants can also be cultivated (Harlan, 1992). "Crop" comes from Old English and has a Germanic origin but ignores the importance of landscape domestication in Europe, where the "fruitalization" of the Mediterranean landscape occurred (González Bernáldez, 1992). It also ignores the importance of forest domestication in Asia, which is a process of co-domestication of trees, mostly fruit bearing, and forests (Wiersum, 1997). Hence, in a region with even more trees than Europe and Southeast Asia (Michon, 2005), it seems appropriate to expand our definition to include what the ecologists call the "standing crop," the amount of biomass produced in a given landscape or ecosystem, with the caveat that the biomass is of importance to people, both past and present.

With our terms defined, we can now consider crop domestication in Amazonia and address several questions: When and where did the domestications start? How many were domesticated to some degree? Where were the domesticated crops at the time of European conquest? Which were most important at conquest and which are important today?

When Did the Domestications Start?

This is a question for archaeology. Unfortunately, few Amazonian archaeologists have looked at botanical questions like this in sufficient detail. There is, however, evidence about Amazonian crops along the Pacific coast of Peru, where environmental conditions are excellent for plant preservation. The earliest archaeological remains of Amazonian crops date to between 10,000 and

8,000 years ago and are of manioc, sweet potato (*Ipomoea batatas*, Convolvulaceae), and hot pepper (*Capsicum* spp., Solanaceae) (Pearsall, 1992). None of these are native to the Pacific slopes of the Andes, so we can assume that domestication started much earlier in Amazonia, perhaps as early as the Ecuadorian case, which was with a squash, *Cucurbita ecuadorensis* (Cucurbitaceae), that was later abandoned in favor of other domesticated squashes (Piperno & Stothert, 2003). The earliest Amazonian archaeological site with botanical evidence is Pedra Pintada, in Monte Alegre, Pará, along the lower Amazon River, where the earliest human evidence is dated to 11,200 years ago and botanical remains suggest a broad-spectrum economy (Roosevelt, Lima da Costa, Lopes Machado et al. 1996), including several species with incipiently domesticated populations today, such as Brazil nut (*Bertholletia excelsa*, Lecythidaceae). The earliest site that suggests landscape domestication is Peña Roja, along the Caquetá River, southeastern Colombia, where another broad-spectrum economy that developed by 9,000 years ago used numerous palms, among which milpesos (*Oenocarpus bataua*, Palmae) became continually more important with time (Mora, 2003, 2006). Milpesos also has incipiently domesticated (Clement et al. 1999a) and is hyperdominant in some parts of Amazonia (ter Steege et al. 2013), including along the Caquetá River. From this scanty and widely dispersed evidence, we can hypothesize that both landscape and plant population domestication started quite early in Amazonia, probably as soon as people settled into the landscape since they were part-time domesticators and horticulturalists. Food production, which depends upon cultivation of plant populations in the process of domestication, started by about 11,000 years ago in various parts of the Neotropics (Piperno, 2011), including at Peña Roja between 9,000 and 8,000 years ago (Mora, 2003, 2006), where leren (*Calathea allouia*, Marantaceae) and a *Cucurbita* appear to be the first cultivated plants. As more archaeological sites are studied by archaeobotanists in Amazonia, this first date will probably be considered late.

Where Did the Domestications Start?

This is a question for biogeographers and geneticists, as well as archaeologists. A crop will be brought into the domestication process where four chance events meet: an individual plant or small group of plants with a useful product that catches the eye of a gatherer and is good enough to take back to camp; a place where the useful product's propagule (seed or bud with subtending tissue) can germinate and grow, often in a dump heap (Anderson, 2005); the useful product of this propagule will be as good or better than the original plant's; and the eye of the same or another gatherer who will continue the sequence by selecting and propagating again. As Darwin (1859) pointed out, none of this needs to be intentional.

Since the process of domestication starts with the selection of a single individual or small group of individuals that are then propagated, the origin of domestication can be identified by comparing domesticated populations with a representative sample of wild populations from across the species' distribution. A nice example is the identification of the origin of domestication of manioc in southwestern Amazonia (Olsen & Schaal, 1999, 2001; Olsen, 2004). Wild manioc (*M. esculenta* ssp. *flabellifolia*) occurs in open forests across southern Amazonia; the world core collection of domesticated manioc at the International Center for Tropical Agriculture contains the same alleles in three different genetic markers as are found in southwestern Amazonia, but not in southeastern Amazonia, effectively delimiting the center of domestication. A recent review found that the majority of early crop domesticates originated in the periphery of Amazonia (Clement et al. 2010), especially in open forests along the southern and northern peripheries, as hypothesized by numerous students of Neotropical crop domestications (see Piperno, 2011), but also in more humid forests in the western periphery, which are also open forests because of their dynamics. This is true both for crops that became domesticated in cultivated landscapes, such as manioc, sweet potato, leren, and *Capsicum* peppers, and

for incipient domesticates that are more common in promoted landscapes, such as the assaís, milpesos, and Brazil nut.

How Many Were Domesticated to Some Degree?

This is a question for botanists, plant breeders, and archaeologists. A survey of the Neotropical historical record about natural resources from conquest to eighteenth-century ethnographies (Patiño, 1963, 1964, 1967), as well as other compilations, permitted the identification of at least 138 plant species with populations domesticated to some degree present in Amazonia at and shortly after European conquest, of which 83 are native to greater Amazonia. The others were introduced from Mesoamerica, the mid-elevation Andes and elsewhere in lowland South America (Clement, 1999a). Among the 36 incipient domesticates, 35 are fruit-bearing trees that are more common in promoted landscapes. Among the 28 semi-domesticates, 24 are fruit-bearing trees, some common in promoted landscapes and some in managed and cultivated landscapes. Among the 19 domesticates, nine are fruit-bearing trees or woody perennials with other uses, all dependent on managed and cultivated landscapes. Overall 82 % of the native species with populations domesticated to some degree are perennials, which is not surprising in the world's largest tropical forest biome. There are likely to be many more incipient domesticates and possibly more semi-domesticates, since the identification of most of these depended upon historical records and ethnographies, almost always prepared by non-botanists and never by plant breeders, who create collections of plant genetic resources in preparation for breeding and which allow the careful comparison of morphological and now genetic differences that are essential to identify components of the domestication syndrome of each species (Meyer, DuVal, & Jensen, 2012).

Where Were the Domesticated Crops at the Time of European Conquest?

This is a question for botanists, plant breeders, biogeographers, and archaeologists. The majority of the world's crops have distributions that cover large geographic areas that are often far from the crop's origin of domestication (Harlan, 1992), which is one of the reasons that the search for crop origins is often difficult. The crops native to Amazonia are typical of the trend observed at the world level.

In 1541, when Francisco de Orellana and his expedition descended the Napo and Amazon Rivers for the first time, thus initiating the European conquest of Amazonia, the majority of the largest indigenous societies were located along the major white water rivers of the basin (Heckenberger and Neves, 2009), with several others in the southern periphery, notably in the upper Xingu River basin, in central Brazil, and the Llanos de Mojos, in lowland Bolivia. These large populations produced all, or at least the majority, of their subsistence needs and depended upon an ample assortment of cultivated varieties of native and introduced crops (Clement, 1999a; Piperno, 2011). It is a truism in food production systems that monoculture stimulates the evolution of pests and diseases, which are managed today with pesticides. Before the advent of pesticides, monocultures were much less common, and pests were managed by using polycultural and polyclonal systems and an abundance of cultivated varieties (Clement, 1999a; Denevan, 2001). It is no surprise to find the largest concentrations of crop genetic resources where there were large human societies (Clement, 1999b; Clement et al. 2010). There are exceptions to this trend, of course. One is the Negro River, the major northern tributary of the Amazon River, with nutrient-poor waters and soils, but abundant socio-diversity, which selected and maintained numerous crop varieties (Clement, 1999b). It is important to recognize that these are centers of accumulation of crop genetic diversity and not centers of origins of domestication. In Amazonia, these two types of

centers are clearly different, whereas in other centers of crop genetic diversity identified by the important Russian geneticist and biogeographer of the early twentieth century, Nicolay Vavilov (Dorofeyev, 1992), they are often less clearly differentiated.

Which Were the Most Important Crops at Conquest?

This is another question for archaeologists and historians. Francisco de Orellana's expedition reported an abundance of manioc and maize (*Zea maiz*, Poaceae) flour stored in villages along their route, which they sometimes received as presents but most often stole (Carvajal, 1894). Manioc continues to be important today, but maize nearly disappeared during the decimation of Native Amazonians during conquest and colonization (Clement, 1999a). Orellana's expedition also reported that all villages were surrounded by orchards, which certainly started in the home gardens behind the malocas and extended for several kilometers, gradually becoming managed forests and later promoted forests (Levis, Souza, and Schietti et al. 2012). The importance of orchards helps explain the number of domesticated fruit trees, while the managed and promoted forests contained mostly semi- and incipient domesticates. For any plant to contain domesticated populations, those populations must be culturally and economically important enough for people to select, propagate, cultivate, harvest, and process into food and other useful products. The most important crops were the 19 domesticates, with numerous edible fruits (including pineapple, *Ananas comosus*, Bromeliaceae; peach palm, *Bactris gasipaes*), several roots for starch (including manioc and sweet potato), condiments of various types (including hot peppers), an important colorant (annatto – *Bixa orellana*, Bixaceae), an assortment of stimulants (including cocaine, *Erythroxylum coca*, Erythroxylaceae; tobacco, *Nicotiana tabacum*, Solanaceae; guaraná – *Paullinia cupana*, Sapindaceae), a single seed crop (peanut – *Arachis hypogaea*, Fabaceae), and even the edible starchy stem of a vine (*Cissus gongylodes*, Vitaceae) (Clement, 1999a).

The subsistence economies of the largest, most complex societies depended substantially on food and other products from the domesticates and many semi-domesticates, but they also continued to extract food and other products from forests, all promoted or managed to some degree, as well as fishing and hunting for animal protein (Clement, 1999a; Heckenberger and Neves, 2009). The hyperabundance of the assaís and milpeso palms are the clearest examples of anthropogenic forests that provided important food resources. The Marajoara society of Marajó Island, in the Amazon River estuary, may have depended more on the floodplain assai (*E. oleracea*) than on cultivated domesticates (Schaan, 2011).

Which Are Important Today?

This is a question for modern economists. It is often observed that modern global society depends upon 30 crops (Harlan, 1992). Three of these originated in Amazonia: manioc, sweet potato, and peanut. Among the important tropical fruits, pineapple is the second most important (Chang, 2011), after banana (*Musa* spp., Musaceae), which is included among the 30. However, a large fraction of global society certainly considers that the most important crop from Amazonia is cacao (*Theobroma cacao*, Malvaceae), used to make chocolate, which was invented in Mesoamerica (Foster & Cordell, 1992).

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Crops in Pre-Columbian America

Murdo J. Macleod

Before the European invasion of the Americas, the native peoples harvested a large variety of crops under many types of agricultural and gathering regimes.

Dense concentrations of people had existed for centuries in Mesoamerica and Andean America, and had evolved complex societies of agricultural peasantry and stratified urban elites. These peoples, in fact most Native Americans, had selected and adopted a miracle grass, maize (*Zea mays*), which reached yields of over one hundred to one in regions of good soils, intensive irrigation, and monoculture such as the *chinampas* or "floating gardens" of the central valley of Mexico. These high yields led to maize dominance in many diets, and the societies which evolved around this cereal may have resembled those of paddy rice China, which had highly intensified, quasigardening systems, rather than those of Europe or Africa, which had lower yielding but more diversified systems associated with wheat, barley, millet, and sorghum.

Maize was often associated, especially in Mesoamerica, with various varieties of American beans, especially *frijoles* of the genus *Phaseolus*, which climbed the maize stalks; with squashes (*Cucurbitae*) and their relatives; and with chili peppers (*Capsicum*), often planted between the maize stalks. The insufficiencies of this basic diet led to heavy foraging and to the harvesting of unoccupied areas and forests. In fact, even in settled societies there appears to have been a harvesting continuum from irrigated maize gardens to collecting, often in forests which were themselves results of centuries of human selection and propagation. Thus, the modern student finds, paradoxically, intensive monoculture, plus slash and burn, plus areas of great biodiversity, all used by the same population.

Tubers of many kinds were widely cultivated but were somewhat more geographically restricted than the maize, beans, squash, and chili complex. Yams (genus *Dioscorea*), cassavas, or maniocs (*Euphorbiacae*), some of highland origin, were intensely planted, and eaten after conversion to flours and breads, in tropical zones such as the Caribbean and the Amazon Basin. In many such regions, cassava was the staple diet. Musae (bananas and plantains) also appear to have been or become a staple in parts of the tropical lowlands, but scholars dispute their origin, some claiming that they are not native to the Americas.

In the Andes, tubers were also of great importance. Varieties of potatoes (*Solanum*) have been cultivated there for about 8,000 years, selected by humans for the many microenvironments of the mountain tropics. Andean farmers sometimes plant as many as 200 varieties in a single field, although most are being phased out in favor of the modern selected potatoes. Several other tubers were cultivated in highland America, such as *achira* (*Canna edulis*); *arracacha* (*Arracacia xanthorrhiza*); *jicama* (*Pachyrhizus erosus*); *machua* (*Tropaeolum tuberosum*); ova (*Oxalis tuberosa*); and *ulloco* (*Ullucus tuberosus*), still a staple in parts of the Andes. This area also produced tubers and grains which could be grown at great altitudes in poor climatic and soil conditions. Maca (*Lepidium meyenii*), a tuber, can be grown just below the snowline, as can *kaniwa* (*Chenopodium pallidicanle*), and the better known quinoa (*Chenopodium quinoa*), both cereal grains rich in proteins and other nutrients.

Several other crops in America were traded widely before the European arrival. Cacao (*Theobroma cacao*), probably of Amazon origin, was known in the regions today called coastal Ecuador and Venezuela, but it was in Mesoamerica that cacao reached its greatest prominence. Planted along the Pacific coast from Colima to El Salvador, and in parts of Honduras, Tabasco, and Veracruz, cacao was important in trade, tribute,

and ritual. In some parts of the region it was used as coinage, and there are also reports that in some states its consumption was limited to the aristocracy. Tobacco (*Nicotiana tabacum*) was somewhat different. Although traded in many regions of America, its use may have been limited to ceremonial occasions.

Mesoamerica also produced vegetable and insect dyes, especially blues from indigo (*Indigofera tinctoria*) and reds from cochineal (*Opuntia cochinellifera*). Both items were traded, paid over as tribute, and used for ceremonial purposes. American cotton and thread from cactus were parts of textile trades and tribute.

European invasion and its consequences had widespread effects on American crops and their diffusion. The catastrophic fall of the native population and the introduction of large- and medium-sized domesticated animals, such as horses, cattle, sheep, goats, and pigs, caused abandonment of fields, destruction of crops, and the disappearance of many forms of ground cover. European need for wood for construction, shipbuilding, and fuel led to the cutting down of forests and the crops harvested in them. Colonial demands for uniformity in taxation caused peasants to give up the growing of marginal cultigens, or ones unfamiliar, distasteful, or useless to the dominant culture. The introduction of animals, and of plants such as wheat, citrus trees, and sugarcane, all cultural preferences of Europe, took up agricultural lands, and drove out native species.

Many scholars have stressed the more positive side of these intrusions and exchanges. Introduced crops such as wheat and animals such as cattle transformed the American diet, and the vast quantities of wheat grown on the prairies of the United States and Canada, and on the Pampas of Argentina, have fed large numbers of people in many parts of the world.

The more positive view also emphasizes the diffusion of American plants throughout the world, while admitting that the impact of some of these exports has been noxious (tobacco) or ambivalent. The potato, for example, the introduction of which to northwestern Europe met some resistance at first, was blamed by some for the Irish famine. Its high yields and ease of cultivation led to a monoculture, rapid population growth, then famine and mass emigration – ironically to the Americas – when the potato crop failed. The advantages brought, nevertheless, by this productive, nutritious, human selection to the everyday diet of peoples living in the temperate zones are, of course, immense.

Some American crops, while having a generally beneficial impact when exported, had their "booms" modified or cut short by new technologies or crops. The two great American dyes, indigo and cochineal, after enjoying a century or two of flourishing trade, were destroyed by the invention of aniline dyes in the mid-nineteenth century. Sugarcane, not originally an American plant, nevertheless achieved great importance only when exported to the Americas. Plantation sugar, always prized by Europe but historically in short supply because of poor access to tropical areas and labor, boomed when northeast Brazil and the colonial islands of the Caribbean combined tropical climates, African slavery, intensified production, and reasonably close markets, and began to export huge shipments. Sugarcane transformed much of the world's diet, and was an important fuel for the industrial and commercial revolutions of the nineteenth century. Although it continued to be of importance its monopoly was destroyed by the rise of beet sugar.

There can be little doubt, however, about the continuing beneficial impact of the diffusion beyond the Americas of many of the native crops. Maize, with rice one of the world's two "miracle" cereals as far as yields are concerned, has spread, now largely as a hybrid, throughout the world, and its productivity has increased since the "Green Revolution." It has become a staple in parts of the Mediterranean, the Balkans, Africa, and South Asia, and continues to be the largest food item for the masses in many parts of Latin America.

Some American crops required modification or additions before their use expanded. Cacao did not suit European tastes when first encountered; indeed it was repugnant to many, until people

learned to add sugar and vanilla. After Swiss and Dutch houses learned the process of making milk chocolate, cacao became an item of world diet, and West Africa is the main producer today.

Indeed, so pervasive today are some of the high-yielding American crops that their pre-Columbian American origins have been forgotten by the general public. Indian curry and Hungarian paprika, both based on American chili peppers, Italian tomato sauce, Irish potatoes, West Africa *ogi* and *kenkey* (maize doughs), and Swahili *posho* (maize meal), Turkish tobacco, and Swiss chocolate, are now thought of as age-old, integrated parts of regional and national cultures far from the Americas.

See Also

- ► Agriculture in South and Central America
- ► Food Technology in Latin America
- ► Potato: Origins and Conservation of Potato Genetic Diversity
- ► Sugar in Latin America

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Cuneiform

Carol F. Justus

Cuneiform was the script used throughout the Ancient Near East from the fourth to the first millennium BCE. Although a hieroglyphic script came to predominate very early in Egypt, the international second millennium correspondence of the Egyptian Sun King, Iknaton, used the cuneiform script. In the last millennium BCE Mesopotamian art depicts a set of scribes, one writing with a stylus on clay tablets, another on parchment. This later overlap between the use of parchment and clay as writing material foreshadowed the demise of cuneiform, the script by means of which literacy as a technological advance spread throughout the ancient world from early Mesopotamian sites such as Uruk in the lower Euphrates River Valley and Susa in what is now Iran.

The Script Form

Cuneiform (from Latin cuneus "wedge"; cf. German *Keilschrift* "wedge-script") is so named because of the wedge-shaped signs which make up the characters of the script. A reed stylus created these signs that resemble the head of a nail. Pressing one corner of the stylus into the damp clay of the tablet made a *Winkelhaken* or corner wedge ( ). This corner wedge could be elaborated by adding a vertical ( ) or horizontal tail ( ), or by tilting the tail at an angle. These basic shapes combine to produce the more than 700 signs of the cuneiform writing system. Cuneiform signs are read left to

right, as are western European alphabetic symbols.

Alphabets used to write modern Western languages reduce those languages to writing on the principle of one sound to one written symbol. The principle underlying the cuneiform system was by no means so simple. A single sign might have phonetic or logographic values. A corner wedge alone could, as a syllabic unit, represent the syllable sound of "u" as in "U-gan-da" or, as a logogram, refer to the word for the numeral "ten". Two raised corner wedges combined with a vertical wedge ( ) form the phonetic syllable "ud" which also had the logographic meaning "day". While vowel sounds had a one-to-one correspondence with a sign as in "a, i, u": "a" ( ), "i" ( ), and "u" (), there were no signs for consonants such as "p", "t", "k", or "m". Cuneiform signs had phonetic values as syllables, so there were signs instead for "pa, ta, ka, ma, pi, ti, ki, mi" and so on. But a sign also had a logographic value as in the case of *ud* "day". This logographic-syllabic principle underlying the cuneiform script, unlike that underlying an alphabet, used signs to refer either to entire words (logograms) or to phonetic (syllabic) units.

The syllable sign "ud" is typical of signs that refer to vowel plus consonant sequences. Cuneiform also had syllabic signs for consonant-vowel sequences, e.g. ( ) "di", () "gi", or () "ni", and, less frequently, for consonant-vowel-consonant sequences: () "tar" or () "kur" (Table 1).

This system of writing thus easily recorded a language with consonant-vowel sound patterns and consonant clusters in the middle of a word, but not words which begin or end with consonant clusters like "st", or "sk" as in English "stop, skate, nest" or "desk".

While cuneiform syllabic signs often represented speech sounds, the same sign might also have non-phonetic uses as well. In addition to syllabic (phonetic) uses, signs might function as determinatives as well as logograms. As a determinative, a cuneiform sign preceded (or followed) one or more sets of signs without any phonetic value. The non-phonetic determinative merely signaled to the reader that a word in question was of a particular semantic type. Typically, the determinative for "female" preceded a woman's name, the determinative for "male" a man's, or the determinative for "deity" the name of a god or goddess. Used as a logogram, as noted, a cuneiform sign stood for an entire word. Thus, either the single sign () or the syllabic sequence *ni-in-da* might stand for Sumerian "bread". Likewise, "deity" might be written logographically in a Sumerian text using the "an" sign (nr. 13) or syllabically with the sequence *di-in-gi-ir*. Such dual mechanisms illustrate not only the relation between logographic and phonetic representation of words but also something of the syllabic structure of the Sumerian language which had word-medial (*-nd-* and *-ng-* in *ninda* and *dingir*) but not word-initial or word-final consonant clusters.

Scribes often used signs logographically for the lexical content of common words and syllabically for grammatical markings such as the possessive of a noun. Thus, "of god" in Sumerian might be written phonetically as *di-in-gi-ir-ra* (*dingir* plus the possessive suffix *a*) or logographically with the "god" sign plus the syllabic sign, *-ra*. Transliteration conventions using the Roman alphabet distinguish among determinative, logographic, or syllabic uses of cuneiform signs on a tablet by using lower case, upper case, and raised letters. Signs used phonetically are transliterated with lower case letters; signs used logographically but interpretable on the basis of a Sumerian word are transliterated using capital letters for the Sumerian word form. The Sumerian scribe's writing of the logogram for "god" plus syllabic *-ra* would thus be transliterated DINGIR-*ra* to distinguish it from a scribe's entirely syllabic rendition, *di-in-gi-ir-ra*.

Determinatives are transliterated as raised sequences, either before or after the "determined" word. Characteristically the plural determinative follows, while others often precede. Thus, "gods", written with the logogram for "god" () plus a plural determinative whose Sumerian phonetic value was "mesh" (), might be transliterated in Roman letters DINGIR ^{MESH} and translated "gods". Similarly, the Sumerian sun god, Utu, would begin with the determinative

for "deity" ( ) and continue with the name, Utu, written syllabically ^{DINGIR}U-tu. However, the sun god's name was usually written logographically using the logogram for "day", ^{DINGIR}UD ( ), transliterated ^{DINGIR}UTU (Sungod). To bring the use of cuneiform signs full circle, one might recall that the "god" sign (), besides its logographic reference to the Sumerian word, *dingir* "god", also had a syllabic reading, *an*. For a scribe, the same sign thus had multiple values. The sign () had a phonetic (syllabic) value *an*, a logographic value "god" (Sumerian DINGIR), and a non-phonetic use as the determinative for "deity" to which modern scholars assign the phonetic value, *dingir*, for purposes of transcription.

Like determinatives, which had no phonetic counterpart in the speech represented by cuneiform signs, horizontal lines were often drawn across the tablet as a kind of punctuation aid. Because the structure of the languages written in the cuneiform script was very different from English, punctuation principles might also be expected to vary. In fact the scribes' horizontal lines across the tablet probably marked something corresponding in part to our sentences and partly to our paragraphs. These scribal lines occur from earliest Sumerian tablets down through adaptations of cuneiform to write Semitic and Indo-European languages.

Languages Written in Cuneiform

Questions about the range of sounds that written symbols might need to distinguish, and indeed which units of language should be represented by individual signs, have concerned linguists seeking to reduce languages to writing. Western European languages often solved these problems by borrowing the Roman alphabet. Cultures of the Ancient Near East borrowed the cuneiform script, as the alphabet did not yet exist in the third millennium BCE. Cuneiform scribes thus dealt with issues of defining the linguistic units to be represented by altering a system of cuneiform signs already in use to write Sumerian. Scribes in fact used the cuneiform script to write languages that differed from Sumerian. They then had to adapt the script to fit the needs of the languages they spoke. The words of some of the languages had long series of suffixes, for example, while others used word-internal vowel changes much as English does in "sing, sang, sung" or "stand, stood", and Indo-European languages had word-initial and word-final consonant clusters.

A major adaptation of cuneiform was for the East Semitic Akkadian that served as the basis for the spread of cuneiform throughout much of the Near East. Besides Old Akkadian, which had its own conventions for phonetic representations using the cuneiform script, major East Semitic languages include the Old Babylonian in which the southern Mesopotamian Code of Hammurapi was written and Old Assyrian, which records the northern merchant trade between Assur and Anatolian Kanesh (near modern Kayseri, Turkey) even before the time of Hammurapi. Babylonian and Assyrian continue in ever-changing regional forms for nearly 2,000 years as Middle Babylonian, Middle Assyrian, Neo-Babylonian, and Neo-Assyrian. To the east of Mesopotamia the ancient language of Susa, Elamite, also used cuneiform, while Hurrians in Northern Mesopotamia, Syria, and Anatolia adapted cuneiform at different times to write their language. In second millennium Anatolia, the scribes of Hattusa used cuneiform to write Hittite, Luwian, and Palaic, Indo-European languages related to Greek, Latin, and the Germanic language family from which English is descended.

When scribes adapted cuneiform for use in writing other languages, some things changed more than others. While the signs often came to have peculiarly local values in different scribal schools, the most constant aspect of the cuneiform script was its core repertoire of determinatives and logograms. Where cuneiform was used, determinatives such as those for male, female, deity, land, and plural remained the same. Logograms for basic vocabulary, for god, ox, sheep, child, king, mountain, and river, also remained constant. The Akkadian scribe, for example, now had all the options available that the Sumerian scribe had, plus those that involved the phonetic

representation of Akkadian. Akkadian nouns had three different forms depending on whether they were used as subject or object in the sentence, or as a possessive. The Akkadian word for "god" was thus *ilum* (nominative), *ilam* (accusative), or *ilim* (genitive), written as phonetic *i-lu-um, i-la-am, i-li-im* or logographic DINGIR-*lum*, DINGIR-*lam*, DINGIR-*lim* where syllabic signs differentiate case, or simply DINGIR, if the context was clear without the case ending.

When cuneiform spread via an Akkadian-based scribal school, scribal practices also spread. Thus, sign sequences were now often interpretable, not only on the basis of recognizing Sumerian, but also Akkadian, words. This created a further complication for scholars transliterating the tablets into a Roman alphabet. Instead of signs interpretable as Sumerian logograms (Sumerograms in capital letters), there are now signs interpretable as Akkadian logograms (Akkadograms) which scholars transliterate using italic capitals. Since the Hittites borrowed the script as a form of Akkadian cuneiform, Hittite scribes had still more options for writing "of god". While the Sumerian scribes wrote "of god" as phonetic *di-in-gi-ir-ra* or logographic DINGIR-*ra* and the Akkadian scribe used phonetic *i-li-im*, logographic DINGIR-*lim* or DINGIR-RA-*lim*, the Hittite scribe could write phonetic *si-u-ni-ya-as* (Hittite "god": nominative *sius*, genitive *siunias*), Sumerographic DINGIR-(RA), Akkadographic *I-LIM*, or some combination, DINGIR-(RA-)*LIM* or DINGIR-(RA-)*LIM-as*.

The Origin of the Cuneiform Script

The earliest attested use of cuneiform as a developed system of symbols to write a language was its use to write Sumerian ca. 3100. Modern Japanese, which has borrowed Chinese (logographic) kanji characters as a basis for reducing Japanese to writing, likewise uses syllabic symbols to augment logographic symbols. Because the Japanese syllabic symbols (*hiragana*) are an independent Japanese invention to adapt the Chinese script to a language structure for which the kanji characters were inadequate, scholars have hypothesized that Sumerian, with its logographic-syllabic script, represented an adaptation of an earlier "Proto-Tigridian" script of which we have no record, one used for a pre-Sumerian language of the Tigris river valley. Studies in the origin of writing, however, suggest that writing emerged as a new technology in what became the Sumerian city of Uruk.

The forerunners of the earliest cuneiform tablets were "impressed" tablets, tablets impressed first, not by the stylus which came to be used to write cuneiform, but by small clay artifacts known as tokens. The token-impressed tablets were economic documents recording amounts of various commodities that the society stored or transferred. Discrete symbols for commodities such as sheep, barley, or jugs of wine and oil were impressed on to the tablet. At first repetitions of the sheep symbol, for example, referred to the quantity of sheep in question and repetitions of the "oil jug" impression designated the quantity of oil. As the technology for writing and enumeration matured, forms became stylized to reflect changes in the thinking about the content. Concepts of quantity evolved separately from those for commodity, and both became increasingly abstract. What began as impressions of commodity signs and repetitions of the same sign to indicate quantities evolved as two sign types, "numerical signs" and pictographic signs, that developed independent logographic and syllabic values. "Numerical signs" were so-called before it was clear that their earliest forms did not stand for the abstract numeral values of today but only came to have numerical values as the "systems of numeration" evolved. Originally the 60 shapes of the "numerical signs" stood for values in a measure unit system that was specialized for a particular commodity or class of commodity. Sign values varied depending on the commodity quantified much as traditional measure units such as "foot", "inch", "bushel", "cup", and "quart" still do. While there are 12 in. in a foot and four cups to a quart, a "foot" does not have the abstract numerical value 12 nor quart the value 4. Quantity values were also relational

Cuneiform, Table 1 Cuneiform signs and their sign list keys (cf. Borger or Labat)

Numerical key	Usual value	Sign shape
411	u	
480	dish	
1	ash	
381	ud	
579	a	
142	i	
457	di	
85	gi	
231	ni	
12	tar	
366	kur	
597	NINDA	
13	an	
533	mesh	

within the system for measuring commodities; they did not yet refer to abstract numerals.

Over time, the early accounting systems of the Sumerian city states that had used older systems of weights and measures with local values became standardized on the sexagesimal basis of factors 6 and 10. With further standardization on the base ten of the decimal system, the way was paved for the abstraction of number and the association of abstract numerical values with numeral words and signs. Calculation of amounts of commodities in terms of measure units and "numerical signs" replaced the older one-to-one calculation reflected in the early repetitions of impressed commodity symbols, and both are now mostly replaced by systems of abstract numerals. The specialization of script signs as "numerical signs" separate from commodity signs reflected an early stage in this evolution. In this respect, the evolution of cuneiform writing is inseparable from the evolution of early calculation and counting as the evolution of shapes took place as part of the evolution of the new meanings that motivated that evolution.

Commodity unit shapes developed independently of shapes for "numerical signs" when, instead of impressing the token into the clay, the scribe used a stylus to draw the shape of some tokens but continued to impress other shapes, some composite or with added lines. Drawn and impressed shapes that developed logographic and syllabic values became more and more abstract when the corner of a reed stylus came to create wedge-shaped cuneiform signs (http://www.utexas.edu/cola/centers/lc/numerals/numerals.html).

Over the millennia in which cuneiform was used, the shapes of the signs evolved from more pictographic forms to highly stylized symbols. Later Ugaritic use of wedge-shaped signs as an alphabet broke with the cuneiform tradition in assigning new values to sign forms.

Early Non-cuneiform Scripts

The existence of other early scripts in the Ancient Near East attests to the rapid spread of literacy and numeracy. While Egyptian hieroglyphs are clearly independent script forms, the basis for reducing the early Egyptian language to writing is probably not independent of the new technology which arose in Mesopotamia as a response to economic and lifestyle changes involving the storage and transfer of surpluses of essential commodities. In the second millennium too a hieroglyphic script, Hieroglyphic Luwian (at first known as Hieroglyphic Hittite) developed independently in Anatolia and North Syria. This

Luwian Hieroglyphic and the cuneiform script coexisted in different functions. The local hieroglyphic script recorded royal inscriptions in the Luwian language on stone monuments but cuneiform was the script of clay tablets. The fact that Hittite cuneiform tablets of Anatolia refer to "old wooden tablets" has led to speculation that hieroglyphic may have been inscribed into a wax coating on wooden tablets. Since none of these waxed wooden tablets has survived, such inferences, of course, remain speculative. The forms of the hieroglyphs are unrelated to the forms of cuneiform signs, but again the two scripts share a common conceptual basis for reducing language to writing. Hieroglyphic Luwian, like cuneiform and Egyptian hieroglyphics, is based on logographic-syllabic principles.

Decipherment

The cuneiform script was deciphered in the nineteenth century as a result of a trilingual inscription found at Behistun in Iran. The languages of the inscription were Elamite, Old Babylonian, and Old Persian, all written in a form of cuneiform. Both Elamite and Old Babylonian were unknown languages at the time, but Old Persian was known from Zoroastrian religious texts. The Old Persian inscription was first deciphered on the basis of hypotheses about the recurring symbols in Old Persian royal names. From there, hypotheses related the signs used to write the Old Persian with signs in the unknown scripts. Little by little, Old Babylonian and Elamite began to be deciphered. With the decipherment of the script came the decipherment and study of the different languages and cultures that used cuneiform to record their history and socio-economic structure. A not insignificant aid in the subsequent decipherment of Sumerian turned out to be the discovery of grammatical texts that Akkadian scribes had developed as pedagogical devices for teaching the learned language of the second millennium BCE, Sumerian, thereby training scribes to support the ever-growing bureaucracy of the ancient world.

Ongoing work on early cuneiform texts and their predecessors is now being catalogued as the Cuneiform Digital Library Initiative (CDLI: http://cdli.ucla.edu/).

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