Takebe Katahiro

JOCHI SHIGERU

Takebe Katahiro was born in 1664 at Edo (now Tokyo). His father, Takebe Naotsune, was a *Yuhitsu* (secretary) of the Shogun. In 1676, when he was 13 years old, he and his elder brother Takebe Kataaki (1661–1716) became pupils of SEKI Kowa (d. 1708) and studied mathematics. The Takebe brothers and Seki Kowa were colleagues in the Shogun's government, and their families were the same rank: 300 *koku*.[1]

Takebe's mathematical works are in three fields. One concerns completing the *tenzan-jutsu* or *endan-jutsu* (lit. addition and subtraction methods, Japanese algebra system), which was created by Seki Kowa. In the second work Takebe created the *tetsu-jutsu* (inductive methods). Using these methods he obtained the formula of $(\arcsin\theta)^2$. In the third, for computing the approximate value of fractions, he solved the Diophanine equations using the *reiyaku-jutsu* (continual division method). Takebe also worked in astronomy and geography.

In 1683, Takebe wrote his first work, *Kenki Sampo* (Studies for Mathematical Methods). The book provided counter-arguments for Saji Ippei's *Sampo Nyumon* (Introduction to Mathematical Methods, 1680). Saji had criticized Seki Kowa's *tenzan-jutsu* system in the *Hatsubi Sampo* (Mathematical Methods for Finding Details, 1674) and solved Ikeda Masoki's problems in the *Sugaku Jojo Orai* (Textbook of Mathematical Multiplication and Division, 1672). Takebe made good use of the *tenzan-jutsu* method for solving Ikeda's remainder problems.

Takebe commented on Seki Kowa's *Hatsubi Sampo* and published the *Sampo Endan Genkai* (Commentaries for Japanese Algebra System), in 1685. This is one of the best books for studying the *tenzan-jutsu* method.

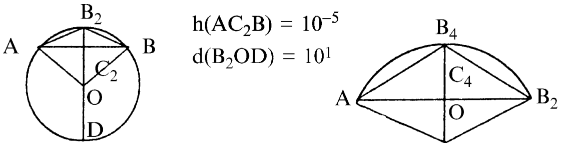
Chinese mathematicians in the Song and Yuan dynasties used counting rods to solve higher degree equations of more than the fourth degree. There were two color symbols in the counting rods: red rods were plus and black were minus. They had no symbols to express power; the position of the rods on the counting board indicated the powers. Therefore, the system could not indicate complex expressions. For example, $1/(x-1)$, that is $(x-1)^{-1}$, was very difficult to indicate by that system. Seki Kowa abandoned the counting rods system and created algebraic symbols, which used Chinese characters for calculation with figures. This might be the first example of creating Japanese mathematics from the Chinese.

Takebe commented on the most important Chinese algebraic text in Japan at that time, *Suanxue Qimeng* (Introduction to Mathematical Studies, Zhu Shijie, 1299). He published the *Sangaku Keimo Genkai Taisei* (Complete Works of Commentaries on Suan Xue Qi Meng) in 1690. Seki Kowa and the Takebe brothers started to compile an edition of the mathematical works of *Seki-ryu*, Seki Kowa's school. After Seki died, Takebe Katashiro continued this work and published *Taisei Sankyo* (Complete Mathematical Manual) about 1710.

Takebe's main work is the *tetsu-jutsu* method, a sort of inductive method. He computed small natural numbers and then predicted infinite numbers. The computation was helped by the algebraic symbols of the *tenzan-jutsu* method. Using these methods, Takebe obtained the formula of $(\arcsin\theta)^2$. He computed the length of curve AB (hereafter s) using the diameter d and the length of straight line AB (h).

Takebe set up $d = 10$ and $h = 10^{-5}$. Then letting the half point of straight line AB be C_2, and the half point of curve AB be B_2, he computed the length of AB_2 (h_2). Then he computed the length of AB_4 as h_4, and continued to compute h_8, h_{16}, h_{32} and h_{64}. Takebe computed h_∞ using a sort of infinity series *zoyaku-jutsu* (extra division method), and obtained h_∞.

$$\left(\frac{s}{2}\right)^2 = 10^{-4} \times 1.000\,000\,333\,333\,411\,111\,225\,396\,906\\ 666\,728\,234\,776\,947\,959\,587\ldots\\ h(\mathrm{AC_2B}) = 10^{-5},\\ d(\mathrm{B_2OD}) = 10^1.$$



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[1] His annual salary was 300 *pyo* (1 pyo was 60 kgs of rice), which is the same as a landlord of 300 person village.

Second, he indicated this value using h and d. The power 10^{-4} is h by d, and the approximate value of the coefficient is 1. Therefore,

$$\left(\frac{s}{2}\right)^2 = 1hd + 10^{-10} \times 0.333\,333\,511\,111\ldots.$$

Then he used the same method. The power 10^{-10} is h^2, and the approximate value of the coefficient is 1/3 using the *reiyaku-jutsu* method,

$$\left(\frac{s}{2}\right)^2 = 1hd + \frac{1}{3h^2} + 10^{-16} \times 0.177\,777\,992\ldots.$$

Takebe continued to compute as above, and he set the series as

$$\left(\frac{s}{2}\right)^2 = A_0 + A_1 + A_2 + A_3 + A_4 + \cdots.$$

He obtained

$$A_0 = hd, \quad \frac{A_1}{A_0} = a_1\left(\frac{h}{d}\right),$$
$$\frac{A_2}{A_1} = a_2\left(\frac{h}{d}\right), \quad \frac{A_3}{A_2} = a_3\left(\frac{h}{d}\right), \ldots$$
$$a_1 = \frac{1}{3}, \quad a_2 = \frac{8}{15}, \quad a_3 = \frac{9}{14}, \quad a_4\frac{32}{45}, \ldots$$

He expanded them to the general series of a_n, which was

$$A_n = \frac{2n^2}{(n+1)(n+2)}.$$

Therefore Takebe obtained the formula

$$\left(\frac{s}{d}\right)^2 = 2\sum_{n=0}^{\infty}\left(\frac{(n! \times 2^n)^2}{(2n+2)!} \times \frac{h^{n+1}}{d^{n-1}}\right).$$

Takebe had no notion of triangle functions. However, if we set

$$\theta = \sqrt{\frac{h}{d}},$$

we can obtain arcsin $\theta = s/(2d)$. Therefore, his formula has the same value as the formula

$$(\arcsin\theta)^2 = 2\sum_{n=0}^{\infty}\frac{(n! \times 2^n)^2}{(2n+2)!} \times \theta^{2n+2}.$$

This work was described in the *Fukyu Tetsu-jutsu* (Inductive Methods) in 1722, and the special manuscript was sent to to Shogun in 1730.

The key method of *tetsu-jutsu* was computing the approximate value of decimal fractions. He named it the *reiyaku-jutsu*, which used the Euclidean algorithm to compute the value of continuing fractions. For example, to try to compute the approximative value of π using this method, we set;

$$\pi_n = 3.1415926, \quad \text{or} \quad 3 + \frac{1{,}415{,}926}{10{,}000{,}000}.$$

First, divide 10,000,000 by 1,415,926; the quotient q_1 is 7 and the remainder r_1 is 88,518. Next, divide the former divisor 1,415,926 by the remainder r_1; the quotient of q_2 is 15 and the remainder r_2 is 88,156. Next, divide the former divisor r_1 by the newer remainder r_2, and the quotient q_3 is 1 and the remainder r_3 is 362. Continuing this algorithm, the quotients are:

$$\{q_1, q_2, q_3, \ldots, q_n\} = \{7, 15, 1, 243, 1, 1, 9, 1, 1, 4\},$$

$$p_1 = 3 + 1/7 - 22/7 > \pi_n,$$

$$p_2 = 3 + 1/(7 + 1/15) = 333/106 < \pi_n,$$

$$p_3 = 3 + 1/(7 + 1/(15 + 1/1)) = 355/113 > \pi_n.$$

$$p_{2k} = q_0 + 1/(q_1 + 1/(q_2 + 1/q_3 + 1/(q_4 + + 1/q_{2n} + 1))) < \pi_n,$$

$$p_{2k+1} = q_0 + 1/(q_1 + 1/q_2 + 1/(q_3 + 1/(q_4 + + 1/q_{2n} + 1))) > \pi_n.$$

The value of p_1 and p_2 had already been computed by the Chinese mathematician, Zu Chongzhi (429–500). Takebe concluded that Zu Chongzhi also invented the same method as his own *reiyaku-jutsu* and Zu Chongzhi's significant figures were seven decimal places, the same as the above computation. He admired Zu Chongzhi and named his book *Fukyu Tetsu-jutsu*; the title was connected with Zu Chongzhi's *Zhui Shu*.

In 1723, Takebe made a map of Japan under the order of Tokugawa Yoshimune, the eighth Shogun, this map is now lost. That year Takebe became a *Yoriai* (adviser) of the Shogun.

Shogun Yoshimune already permitted the import of foreign scientific books in 1720, if they were not related to missionaries. Knowledge of Western astronomy was imported in some Chinese translations. Takebe and his student, Nakane Genkei (1662–1733) translated Mei Juecheng's *Li Suan Quan Shu* (Complete Works of Calendar and Mathematics, 1723) and sent the manuscript (Japanese name *Rekisan Zensho*) to Yoshimune in 1733. It was published and read by many Japanese scholars. Kepler's newest opinion, the elliptical orbit of planets, however, was hidden by the missionaries who advised Mei Juecheng. It became known to the Japanese after Asada Goryu (1734–1799) translated Kepler's (Part 2 of) *Li Suan Quan Shu*.

Takebe was held in honor by Yoshimune, and he became a *Hoi* (Knight), and held successively better positions. In 1733, he retired, and he received a life annuity of 300 *pyo*. He died on July 20, 1739 (August 24, 1739 in the present calendar) at Edo.

Takebe was one of the best mathematicians in Japan. The Mathematical Society of Japan has presented the Takebe Katahiro Prize since 1996.

See also: ►Computation: The Chinese Rod Numeral System, ►Asada Goryu, ►Seki Kowa, ►Mathematics in Japan

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Tang Shenwei

HONG WULI

Tang Shenwei was a medical practitioner of the eleventh century. He was a native of Chongqing, Sichuan Province with the surname Shenyuan, and later he moved to Chengdu in the same province. He was born to a family of many generations of physicians and was an expert in medical science. During the Yuanyou period (1086–1094) of the Song Dynasty, his tutor was Li Duanbo. Tang inherited his tutor's medical knowledge and became quite adept at treatment. He was very virtuous, also he responded to any patient's call and never refused to see a patient, whether rich or poor. The only payment he asked was knowledge about a certain herb or an effective recipe (Tang 1957).

He was especially conversant in the herbal art. He compiled a 32-volume *Materia Medica of Classified Syndromes* which was based on the combination of two other existing herbological works, the *Jia you ben cao* (*Jiayou Materia Medica*) and *Tu jing ben cao* (*Illustrated Classic of Materia Medica*). He added a large amount of new material extracted from the classics of philosophy, history, and other branches of the natural and social sciences, as well as the Buddhist canon, with a total number of 1,746 herbal drugs (Tang 1904). In the field of traditional pharmacology, in addition to absorbing the knowledge inherited from earlier practitioners, he was full of initiative and creativity. Most of his experience was derived from his own long-term practice. He enriched the traditional herbological work by adding processing methods and effective recipes for each herb. Meanwhile, he was also a proficient clinical physician. He created a new style of combining medical practice with herbal knowledge to form the principle of "verifying the drug by recipes", which was quite helpful to clinical practitioners, thus pushing medical science forward a step further. His work was treated as an officially promulgated book on materia medica and circulated for several hundred years (Shang 1989). His working methodology and epistemology were praised and copied by later scholars in the same field. Tang exerted an especially profound influence on the work of the great naturalist of the Ming Dynasty, Li Shizhen.

See also: ▶Medical Ethics in China – Li Shizhen

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Tao Hongjing

FABRIZIO PREGADIO

The Daoist (Taoist) master, alchemist, and pharmacologist Tao Hongjing was born in 456 near modern Nanjing. He served in various positions at the courts of the Liu Song and Qi dynasties until 492. In that year he retired to Mount Mao, the seat of Shangqing or Supreme Purity, a Daoist tradition based on meditation and visualization techniques. The retreat he built on the mountain was to remain the center of his activities until his death in 536.

After his initiation into Daoism around 485, Tao set out to recover the original manuscripts, dating from about one century before, that contained the revelations at the source of the Shangqing tradition. Tao authenticated and edited the manuscripts, and wrote extended commentaries on them. This undertaking resulted in two texts completed in ca. 500, the *Zhengao* (Declarations of the Perfected) and the *Dengzhen yinjue* (Concealed Instructions on the Ascent to Perfection, only partially preserved). These and other works make Tao Hongjing the first systematizer of Shangqing Daoism, of which he became the ninth patriarch.

Since the establishment of the Liang dynasty in 502, Tao enjoyed the favor of Emperor Wu (r. 502–549), on whom he exerted remarkable influence. Shortly after, he began to devote himself to alchemical practices under imperial patronage. His main biographical source, written in the Tang period, has left a vivid account of these endeavors. Along with scriptural sources they testify to the importance of alchemy within the Shangqing tradition, which represents the first known instance of close links between alchemy and an established Daoist movement.

A third text on which Tao Hongjing worked during his retirement on Mount Mao was the *Bencao jing jizhu*, a commentary on the earliest known Chinese pharmacopoeia, the *Shennong bencao*. The original text contained notes on 365 drugs. To these Tao added 365 more, taken from a corpus of writings that he refers to as "Separate Records of Eminent Physicians." Tao's arrangement of the materia medica was also innovative. He divided drugs into six broad categories (minerals, plants, mammals, etc.), and retained the three traditional classes of the *Shennong bencao* only as subdivisions within each section. In a further group he classified the "drugs that have a name but are no longer used [in pharmacology]." Tao's commentary discusses the nomenclature, notes changes in the geographical distribution, and identifies varieties; it also includes references to the Daoist *Xianjing* (Books of the Immortals) and to alchemical practices. With the exception of a manuscript of the preface found at Dunhuang, the *Bencao jing jizhu* is lost as an independent text, but has been reconstructed based on quotations in later sources.

See also: ►Alchemy in China

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Taqī Al-Dīn

SEVIM TEKELI

Taqī al-Dīn, Muḥammad al-Rāṣid ibn Ma^{c}rūf, was a mathematician and astronomer. He was born in Damascus in 1521 and died in about 1585. He wrote several books on mathematics, astronomy, optics, and theology.

The most important of his books are: *Jabr wa'l-Muqābala* (Algebra), *Bughyat al-Ṭullāb min ^{c}ilm al-Ḥisāb* (The Desire of Students for Arithmetic), *Sidrat al-Muntahā fī al-Afkār* (The Nabk Tree of the Extremity of Thoughts), and *Ālāt-i Raṣdīya li Zīj-i Shāhinshāhīya* (Observational Instruments of the Emperor's Catalogue), *Al-Kawākib al-Durrīya fī Bengamāt al-Dawrīya* (The Brightest Stars for the Construction of Mechanical Clocks).

From the point of view of the history of Ottoman science, the most important event of the sixteenth century was the foundation of the Istanbul Observatory, which Taqī founded under the sponsorship of Murād III (1574–1595). This observatory was an elaborate building which contained dwelling places, a library, and offices for the astronomers. It was conceived as one of the largest of the observatories of Islam and was comparable to Tycho Brahe's (1546–1601) Uranienborg Observatory built in 1576, equipped with the best instruments of his time in Europe. There is a striking similarity between the instruments of Tycho Brahe and those of Taqī al-Dīn.

The instruments of the observatory included the following. First there were those originally constructed by Ptolemy: the armillary sphere, the parallactic ruler, and the astrolabe. Then there were those invented by Muslim astronomers, such as the azimuthal and mural quadrants. Taqī al-Dīn invented the *mushabbaha bi'l manāṭiq* (sextant, an instrument with cords for the determination of the equinoxes), which was also an important invention of Tycho Brahe. In addition, he built a wooden quadrant for the measurement of azimuths and elevations, and clocks for the measurement of right ascensions of the stars. The latter was one of the most important discoveries in the field of practical astronomy in the sixteenth century, because in the beginning clocks were not accurate enough to be used for astronomical purposes.

In *The Astronomical Instruments of the Emperor's Catalogue* the author says, "The ninth instrument is an observational clock." The following statement is taken from Ptolemy: "I could have freedom of action if I were able to measure the time accurately. Now our master Taqī al-Dīn, with the help of God, upon the instructions of the Sultan, planned the observational clocks." *In The Nabk Tree of the Extremity of Thoughts* Taqī al-Dīn says, "We constructed a mechanical clock with three dials which show the hours, the minutes, and the seconds. We divided each minute into five seconds." On the basis of his observations, Taqī al-Dīn prepared astronomical catalogues and books.

Hipparchos (second century BCE) used the intervals of seasons for the calculation of the solar parameters. But the variation of the declinations around the tropics in 1 day rendered difficult the correct determination of the beginning of the seasons. In spite of this difficulty, the method was used for a long time. After him, al-Bīrūnī (d. ca. 1048), Copernicus (1473–1543), and Tycho Brahe were interested in this subject, and used a new method called "three points observation." Taqī al-Dīn, a contemporary of Tycho Brahe, says the following in *The Nabk Tree*: "The moderns follow the method of three points observation, two of them being in opposition in the ecliptic and the third in any desired place." This method was an important contribution to astronomy. By using this method, Copernicus, Tycho Brahe, and Taqī al-Dīn calculated the eccentricity of the orbit of the Sun, and yearly mean motion of the apogee. According to Copernicus the eccentricity is 1p 56′; according to Tycho Brahe it is 2p 9′, and according to Taqī al-Dīn it is 2p 0′ 34″ 6′″ 53″″ 41′″″ 8″″″. As compared to modern calculation, Taqī al-Dīn's is the most accurate value. According to Copernicus the annual motion of the apogee is 24″; to Tycho Brahe it is 45″, and to Taqī al-Dīn it is 63″. Its real value is 61″. As far as world astronomy is concerned, Taqī al-Dīn's results can be said to be the most precise in the calculation of solar parameters.

The next important contribution of Taqī al-Dīn concerns the use of decimal fractions, the system of numerals formed from initial letters, used in the Hellenic world. This system hindered the development of algebra.

Al-Khwārizmī (d. 801) presented the decimal system which was inspired by Indians to the Islamic world. The application of this to fractions started with Abū'l-Ḥasan Aḥmad ibn Ibrāhīm al-Uqlīdīsī and continued with al-Kāshī (d. 1437). But its application to astronomic and trigonometric tables was realized by Taqī al-Dīn. Thus the tables of his *zīj* named Kharīdat al-Durar (*unbored pearl*) and a *zīj* were prepared using the decimal system and decimal fractions.

See also: ►Observatories, ►Clocks and Watches, ►Ottoman Science, ►Astronomical Instruments, ►Quadrant

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Technology

ARNOLD PACEY

The development of technology has usually been socially determined, changing in direction as different social formations have emerged. For example, there are important distinctions to be made between, first, small communities of farmers or dispersed groups of hunters with technologies outstanding chiefly for their adaptation to local *environments*; second, the larger kingdoms and empires, whose technology tended to be *engineering-centered*; and third, trading communities and merchants or entrepreneurs with *production-centered* technologies.

An initial problem in discussing technologies of the first kind is nomenclature. Weiner, who has discussed the remarkable protective clothing developed by the Inuit for life in the Arctic, has described these people as "the great pioneers of microclimatological bioengineering." This tribute to the control of body heat loss achieved by Inuit clothing is well deserved but places the skills of Arctic people within the wrong frame of reference. Their technology was environment-centered, not engineering-centered. On the one hand, they were adapting to a very demanding environment; on the other, they were making very efficient use of environmental resources. Thus, the animals hunted for meat were also a source of oil for lamps, bone for making needles and other tools, and the skins, intestines, and fibers from which clothing was made.

Archaeological evidence suggests that the invention of tailored skin clothing adequate to enable people to winter in the Arctic was accomplished in Siberia around 2000 BCE. After that, it was several centuries before oil lamps, houses built of snow, and dog sleds were developed by the people of the Dorset Culture, based on Baffin Island. Later still, improved boats and harpoons were developed by the Alaskan Inuit.

All these inventions, quite clearly, were the work of small, dispersed groups without centralized organization, and all were responses to an exacting environment. Perhaps what we ought also to remember is that for the Inuit, as for most non-Western peoples, the environment was endowed with personal and spiritual meanings, and with magical qualities. It was not merely the object of detached, if concerned, analysis that it has become for most Westerners. Thus, their technology was based on an organic world view.

The same points can be made about peoples inhabiting other environments, such as rainforests, deserts, steppes, or coastal and island situations. The efficiency with which resources were used by such people is illustrated by the estimate that in AD 1500 the Amazon basin supported a somewhat larger population than it did in 1990, yet without the extent of destruction of forest and fishery resources now taking place. Fruits, nuts, leaves, seeds, and roots were gathered for use as food and medicine. Fish and animals were caught, often using poison tipped spears, but with less ecological disturbance.

In some rainforests, notably in Central America as well as in Asia and Africa, people developed a form of agriculture in which a great variety of crops was raised while extensive tree cover was retained. Cereals such as corn in the Americas or rice in Southeast Asia were grown in forest glades with shade tolerant vegetables under trees. Those trees that were left unfelled or were newly planted would be selected according to whether they produced fruit, nuts, timber, fodder, or *materia medica*. Thus, an artificial rainforest was formed in a system often referred to as forest farming, forest interculture, layered gardening or, more recently, agroforestry. The key point – whatever the name – is that there would always be tree cover, and usually other vegetation, to protect the soil from erosion and to retain plant nutrients. By contrast, where rainforest is cleared for conventional western style agriculture, soils become degraded very rapidly.

In Africa, rainforest crop production became widespread only after the banana and Asian yam were introduced on the east coast by Indonesian traders and colonists around AD 400–500. In quite a short space of time, these crops were adopted by many gardeners across the continent, enabling populations in forested areas to increase considerably. In Central America, archaeologists have now shown that the Maya culture used forest farming with high yielding nut trees and manioc (cassava) as major crops around AD 600–900.

Other environment-centered technologies were those of people living in hot, dry, semidesert conditions who evolved sophisticated water conservation techniques. Some of these made use of small structures, such as check dams in gullies and spreader dikes on flatter ground – for example, in northern Mexico and Arizona – or else stone lines on contours (in the African Sahel). Others practiced the careful planning of fields in relation to rainwater catchment areas, and the construction of bunds to channel water and hold it on the land. Among the most elaborate rainwater harvesting systems of this kind were those of Nabataean farmers in the Negev Desert in Israel from about 200 BCE, and comparable systems in Morocco and elsewhere in North Africa. Small dams, river diversions, and the Persian *qanat* (wells linked by a tunnel) were other means of providing irrigation water to crops on a small scale.

Consideration of environment-centered techniques such as these offers a distinct perspective on early technology quite unlike the conventional view based on the materials from which tools were made, namely, stone, bronze, and iron. That view seeks to discover a pattern of tool use and metal-working skill common to all human societies, and ignores the environmental particularism emphasized here. It parallels the modern assumption that the principles of technology are independent of cultural values and underestimates the different ways in which human societies explored the varying surroundings in which they lived. By contrast, a perspective based on environmental adaptation allows one to recognize the extraordinary sophistication of some peoples who nominally remained in the “Stone Age” even in the early twentieth century, including the Inuit and some rainforest communities.

Viewed from another angle, however, the Neolithic period in the later Stone Age does seem to have been a time of particularly important innovation, at least for western Asia. It is associated with the first domestication of crops and livestock, and hence the invention of agriculture, probably associated with the earliest use of some of the water conservation techniques previously discussed. Complementing these innovations were others, such as pottery (and soon after, the potter’s wheel), grain milling, tool-making, and textiles (with the looms on which they were woven). Many of these innovations relate to the domestic sphere of life, and it is likely, therefore, that many of the inventors concerned were women.

It would be a mistake, however, to assume that the invention of agriculture, the domestication of plants, and the appearance of pottery or textiles were unique events, each occurring only once in human history, in one part of Asia and then diffusing to other regions. Independent inventions undoubtedly occurred, just as different crops were domesticated in various places and at different times. For example, about 1500 BCE, corn (i.e., maize) and pottery were both known in Mexico, but not in Peru, where beans and peppers were cultivated. Thus, the two cultures may have developed agriculture independently of one another. Moreover, some plants were still being newly domesticated in the twentieth century, for one reaction to deforestation in Africa has been to cultivate a number of fruits and vegetables that people had collected from the wild until the loss of forest cover threatened their existence.

Reports from Kenya show how modern gardeners, usually women, have selected from wild varieties and have produced strains adapted for garden conditions.

Engineering-centered technologies developed in a very different context. They were characteristic mainly of kingdoms or empires whose labor resources and administration made large scale construction works possible. One view of the origins of engineering is that once agriculture was established, irrigation became necessary in many of the warm, dry countries of western and southern Asia to produce sufficient food for growing populations. The dams and canal systems necessary for irrigation could not have been constructed, it is argued, without recruiting a large labor force, and that in turn could not have been done except in centrally organized kingdoms. In this view, the need for irrigation canals and other hydraulic works dictated the formation of centralized government administrations with the coercive power and management skills needed to organize large scale construction works.

This theory about how hydraulic civilizations evolved does not apply everywhere, however, since empirical evidence shows that in many areas where irrigation was practiced, farmers did the essential earth moving and engineering work themselves, or with their neighbors through local systems of cooperation, but without central organization. This seems to be true for rice culture in China, according to Francesca Bray. Some of the biggest centrally organized engineering schemes prior to AD 605, involving thousands of laborers, were not for irrigation but for construction of transport canals for carrying grain to the capital. However, flood control and irrigation in north China did depend on large scale works, so the evidence is not clear cut.

In Mesopotamia and Egypt, much early irrigation was also on a small scale, dependent on manually operated water raising devices such as the *shaduf*. The type of crops grown and the seasons of cultivation meant that water requirements in early agriculture were much less than after the agricultural revolution of the Islamic period (after AD 700), when crops that demanded more water (including rice) were more widely grown. In Mesopotamia, large scale works were needed at an early date, but in most places it is hard to argue that the requirements of hydraulic management were sufficiently exacting to determine the development of centrally organized states. On the contrary, the prior existence of centralized political power made possible a wide range of construction programs that included fortifications, monuments, and temples, as well as hydraulic works, and it is impossible to say which kind of engineering came first. One of the earliest sites to provide evidence is Jericho, where defensive walls, but also big water tanks, have been found dating from before 6000 BCE. The pyramids of Egypt were among the largest construction projects ever conceived when they were begun about 2600 BCE. But a comparable amount of labor may have gone into embankments and canals built at about the same time for flood control and irrigation by the Sumerians in Mesopotamia. Thus, the evidence does not give a clear picture of hydraulic requirements, rather than other construction works, forcing the pace in either administration or engineering.

That brings us to a second hypothesis about how engineering-centered technologies evolved, suggested by Lewis Mumford and some like-minded commentators. This is the view that such technologies were related to the invention of institutionalized warfare. In early societies, conflicts were sometimes wantonly violent, but some groups had customs that enabled one side to signal a surrender before serious injuries were inflicted. Among a few isolated peoples in Africa and Oceania, conflicts between communities were still like this until recently, and observers note that, if somebody was killed, the combatants were so shocked that fighting immediately stopped. A ceremonial burying of spears and an exchange of cattle or captives would then settle outstanding issues.

Organized, lethal warfare had to be invented, perhaps during the Neolithic period, and possibly following the invention of agriculture, since agriculture made possible denser populations within which tensions could be greater. Also, agriculture produced the economic surplus needed to pay for arms and fortifications. The suggestion is that military institutions evolved from about this time and provided a model of how large bodies of men could be recruited, disciplined, and supervised while constructing fortifications, pyramids or hydraulic works. Many instances can be quoted of the administration of hydraulic installations based on military routines. In later times, at Marv in northern Iran, a water storage dam below the city was looked after by 400 "guards" who minutely regulated and recorded all outflows of water. The head of the water office had more authority than the local police chief, and when repairs to the dam or canals were necessary or when new works were needed, he could call up 10,000 people to do the work.

The development of warfare provided much other stimulus to engineering-centered technology. Mechanized fighting may be said to have begun with the clumsy, four-wheeled Sumerian chariot of about 2400 BCE. The Hittites, whose empire overlapped Asia Minor and Syria, invented some of the first effective siege engines around 1600 BCE and introduced the first iron weapons soon after. Horses were initially used mainly for drawing chariots, their full potential for warfare only emerging much later with the invention of the stirrup and its associated harness. This freed the rider's arms to use weapons while he remained securely in the saddle.

The most famous of military inventions was, of course, gunpowder, known by AD 900, used in rockets by about 1100, and in guns before 1288. These inventions, developed within Chinese military institutions, were stimulated by earlier Indian discoveries about the chemical behavior of saltpeter, and by the use of incendiary weapons for naval warfare in Southeast Asia. The latter often depended on petroleum, obtained from surface oil seepages on the island of Sumatra. Although guns evolved more rapidly in Europe after 1300, China was the source of many ideas for gunpowder siege weapons used in the Arab world, and there were transfers of Chinese firearms technology to Korea and Thailand.

Considerable resources were needed for manufacture of the heavy cannons that had become widespread by 1500, and only the larger Asian empires could afford them in any number – but those that could were then able to expand their territory and consolidate their power. In India, the Mughal Empire's arsenals and gun-casting capability were important for its expansion between 1526 and 1700 In Persia also the new technology had a centralizing, consolidating influence during the reign of Shah Abbas (1587–1627), though his empire depended less on guns than did the powerful Ottoman or Turkish Empire, an exporter of guns and know-how. Given that most cannon were cast in bronze, McNeill has called this period a "second bronze age", referring to "gunpowder empires" not only in connection with Turkish, Persian, and Mughal rule, but also in relation to China and the Russian Empire in Asia.

The ships used in naval warfare and trade in Southeast Asia were of sewn construction, with rattan fiber holding together carefully fitted timbers in a flexible hull suited to landing on sandy beaches. They usually had outriggers and tripod masts to support sails, and regularly crossed the Indian Ocean. The Chinese, meanwhile, were building larger ships whose wooden hulls were held together with iron nails and had watertight bulkheads. China was also developing inland water transport on a large scale. The canals had ramps and spillways for moving boats between one level and another, but also incorporated the first pound locks and lock gates, introduced in AD 983 (a precisely dated invention).

One Western bias in understanding technology is a tendency to focus on the wheel and machines using wheels. But wheels did not always mean progress. Wheeled vehicles were used in the north and west of Africa around 500 BCE, regularly crossing the Sahara Desert. Yet they went out of use later when the camel was introduced, because camels provided much more efficient means of transport in a region with sandy deserts and no paved roads. For parallel reasons, wheeled vehicles were not much used in southern Asia. In Central America, rollers and wheeled toys have been found, but in a region where there were not animals capable of pulling carts, no purpose could be served by developing such devices.

The potter's wheel (and later lathes working on similar principles) were probably the first machines, around 3000 BCE, to use the wheel. Much later, a basic water powered corn mill evolved, with a vertical axle and propeller like blades below the millstones. One view is that this was a Greek invention made about the time of Alexander the Great. Another view, however, is that it arose out of the Hittite tradition of engineering which had earlier pioneered so much military equipment. After the Hittite empire collapsed around 1200 BCE, some aspects of its culture survived in Syria, and itinerant craftsmen perhaps reached Mesopotamia and Iran. It was probably in one of these countries that water mills originated. Since the same type of mill appeared in China not long afterwards, one might reasonably look for its origins close to trade routes with China. As for the introduction of the mill into Greece, this could be a by-product of Alexander's expedition through Iran to the Indus River in 330–323 BCE.

Some thousand years later, Iran was certainly where an early type of windmill was invented. It worked in much the same way as the vertical axle water mill, though mounted in a tower with vents in the walls to catch the wind.

Mumford sees these inventions as part of the tradition of innovation stemming from small dispersed communities rather than from centrally organized states. However, at Baghdad, which had about one million inhabitants in AD 1000, corn milling was carried out by a series of floating mills on the Tigris River which operated continuously, night and day. The water wheels were of the later undershot type, driving millstones through wooden gears. Other uses of water power in Iraq and Iran by AD 1000 were in sugar cane crushing mills, fulling mills, and mills for preparing the pulp for papermaking. Paper manufacturing had been introduced at Baghdad in AD 794, probably with the help of Chinese workmen, and pulping was water powered from about AD 950.

In all these instances, it would seem, we are no longer dealing either with the environment-centered technology of dispersed communities, nor with the labor intensive engineering of powerful centralized states. Rather, we are seeing the emergence of production-centered technologies in expanding industries. An even more striking example can be cited from northern China, associated with the use of blast furnaces for iron production. Methods of achieving high temperatures in furnaces were highly developed in China's porcelain industry as well as in metal smelting. Chinese iron masters had pioneered blast furnaces capable of melting large batches of metal, and output rose steadily to a peak in AD 1078. Moreover, the furnaces were owned and run by independent entrepreneurs whose market oriented, proto-capitalist operations are seen by McNeill as marking a turning point in world history.

More evidence that technology in China was moving into a new phase is provided by the great flowering of mechanical devices that were introduced there in the three or four centuries prior to 1250. They included spinning wheels, silk winding machines, and most striking of all, water-powered mills for spinning and winding thread of a local type comparable to linen. Some improvements in textile technology were due to women innovators, and many businesses were run in an independent, entrepreneurial style.

By contrast, much manufacturing in the major Asian empires was directed toward meeting state requirements for armaments, or the needs of royal palaces for luxury textiles, porcelain, and furniture. The most characteristic unit of production was the royal factory or *karkhana* in Mughal India, or the specialist porcelain factory or arsenal in China. At one time, 4,000 silk workers were employed in karkhanas in Delhi. Some may have been conscripted, and the factories were run in rather the same way as the labor intensive, state-run engineering works mentioned previously. Such factories were highly successful in meeting government requirements for arms or the court's demand for luxury goods, but could not respond readily to a varying market demand. Production for purposes of trade, and especially for export, flourished most markedly where merchants and other entrepreneurs could function independently. By 1700, India had become the world's greatest exporter of textiles, sending its cotton cloth to Europe, Africa, and many destinations in Asia. Both Indian and foreign merchants were involved, sometimes financed by the many Parsi and Gujarati bankers to be found in ports such as Surat.

It should not be thought, though, that proto-capitalist industrial organization was always favorable to the use of machines, water powered or otherwise. The high quality of Indian textiles was achieved by painstaking handwork and a very fine division of labor. British observers noted that cotton cloth would sometimes be worked on by four people for every one employed on the same tasks in Europe. Thus, the remarkably fine muslin produced in Bengal was the result of many detailed processes which would be simplified and reduced to a single operation in the West.

Indian cloth was also noted for the fastness and brilliance of the colors with which it was dyed, mostly using vegetable dyes, such as indigo and madder. However, some inorganic substances were also needed as mordants, and this gave rise to a significant chemical industry. For example, the alum used in madder dyeing was produced in Rajasthan by processing broken shale tipped as waste around copper mines. The shale was steeped in water. Aluminum compounds were separated from copper salts by differential crystallization. Then a reaction with saltpeter produced the alum. These chemical processes were operated on a substantial scale but using labor intensive methods and minimal equipment. Merchants and banks had ample funds to invest in the textile trade, but because wages were low, there was little advantage in financing better production equipment. Instead, most of the capital available was put into building ships to carry exported cloth. Thus, Indian shipbuilding developed to a very high level in the eighteenth century. Ships were built for Indian merchants and foreign traders, and from 1800 for the British navy. Meanwhile, cotton cloth, dyestuffs, and chemicals continued to be produced by laborious manual techniques.

Similarly in China, there were many flourishing industries, often organized on proto-capitalist lines, but the interest in mechanization evident before 1300 was not sustained, and indeed, some machines went out of use. Silks, porcelain, and cotton goods were produced in quantity, but mainly by labor intensive methods in an economy where wages were tending to fall. But, as in India, the production technologies involved are of considerable interest. Moreover, they are quite distinct from the environment-centered and engineering technologies discussed earlier. It is of particular relevance to observe that printing evolved as a production technology in China, and by 1600 had export markets in Korea and Japan. But the content of the books being printed was dominated by the literary interests of the bureaucrats who served the imperial government. Thus, relatively few books were of significance for the dissemination of technical information. It is worth recalling, though, that the first known printed book, the *Diamond Sūtra*, an extract from the Buddhist scriptures, dates from AD 868, and that by the eleventh century a few books on agriculture were being printed. In AD 1044, Zeng Gongliang published the *Wujing zongyao* (Collection of Military Techniques) that quoted the formula for a weak gunpowder mixture, and in 1313 a remarkable work appeared – *Nong Shu* (Treatise on Agriculture) by Wang Zhen – which, among other things, described water powered spinning mills.

But whatever limited writings there were on technical subjects, either in Islamic manuscripts or Chinese printed books, technology depended far more on knowledge, skill, and technique passed from one craft worker to another through processes of observation, personal contact, and apprenticeship. Nonverbal habits of thought and of getting the "feel" for how a process should work were undoubtedly central for innovation and learning.

Nonverbal communication, often in the form of a visual or experimental dialogue, was also the means whereby techniques were passed from one community or culture to another. Confronted with an unfamiliar product or process, a craft worker would not always copy it directly, but would "question" it to try and work out how the same result might be achieved by more familiar means, or how it might be reinterpreted to suit his or her community's culture or resources. Moreover, this dialogue or questioning approach could at times prompt entirely new lines of thought or innovation. For example, between the sixth and tenth centuries AD, the Chinese picked up ideas from India and Persia about chemistry, dyestuffs, textile printing, windmills, suspension bridges, and other matters. These were developed in entirely new ways as a result of being questioned and reinterpreted rather than being copied, and so contributed to some of the best known of Chinese inventions, including gunpowder and printing.

Between 1100 and 1800, and especially after their voyages of discovery began around 1450, Europeans were continually picking up ideas from other cultures: about water clock mechanisms, chemistry, cooking, and glassmaking from Islamic sources; about gunpowder, firearms, printing, and porcelain manufacture from China; and about metallurgy, cotton textiles, and dyestuffs from India. Few of these techniques were directly copied in any detail, but they became part of a dialogue in which Westerners did most of the questioning and learning – and in which they reinterpreted many techniques in terms of the Western enthusiasm for machines and mechanization.

This source of stimulus contributed significantly to the technology of the European industrial revolution, but that in turn brought a change in attitudes and relationships. A sense of technological superiority coincided with a tendency to use non-Western countries as markets for factory made goods and as sources of raw materials. Local manufactures in many parts of the non-Western world therefore declined. One striking feature of the late twentieth century has been a new openness in the West for dialogue with the environment-centered technologies practiced in the rest of the world. But, again, Westerners are reinterpreting everything they learn in terms of their own outlook, discarding the organic and holistic world views of other peoples and fitting everything into an analytical, scientific frame of reference. Thus, Inuit technology has been discussed in terms of "ice alloys" and "bioengineering" whilst indigenous rainforest technologies are being reinvented as "ethnobotany" and "agroforestry".

See also: ►Ethnobotany, ►Gunpowder, ►Paper and Papermaking, ►Colonialism and Science, ►*Qanat*, ►East and West, ►Western Dominance

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Technology and Culture

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General accounts of the history of science and technology (or, more narrowly, of inventions) are scarce. The few that are available are also of fairly recent origin: obviously, the idea of a history of science (where science has been identified with Galilean science) and technology (identified with industrial technology) could not have appeared much earlier than this century. Not many people even know that the word "scientist" was first used by William Whewell in 1833.

Also, most available histories have remained the work of western scholars. This has not been an entirely happy circumstance. On the contrary, it has afflicted these histories with certain methodological and other infirmities which have had the effect of reducing them to mythological works. This is especially so when they are studied with regard to aspects of the history of science, technology, and medicine in the non-Western world.

One of the first is a history of technology and engineering written by Dutch historian Forbes. Forbes's work appeared in 1950 under the title *Man the Maker*. In it, he conceded that technology was the work of humankind as a whole, and that "no part of the world can claim to be more innately gifted than any other part." A few years thereafter, Forbes produced his rich and prodigiously detailed *Studies in Ancient Technology* which set out a remarkable description of the different technologies of Asia, Africa, pre-Colombian America, and Europe. However, it is in *The Conquest of Nature* that his Eurocentric assumptions came to the fore: in that work (as the title itself indicates), Forbes went on to subsume the technological experience of people from diverse cultures under a philosophical anthropology that was unmistakably Western, if not Biblical – the domination of nature myth originating in Genesis. And after a discussion about the grievous consequences of a seriously flawed modern technology, he ended his book promising redemption from the technological genie through the Christian event of Easter. How does one prescribe a text like this to Hindu, Chinese, or Arab readers?

Another influential work of about the same period is *A History of Western Technology* by a German scholar, Friedrich Klemm. In it, Klemm provided a picture of technological development in the West in which non-Western ideas and inventions had no hand at all. The English translation which appeared in 1959 barely mentions Joseph Needham's work on China in the bibliography. Klemm could not have substantiated his interpretation of Western technological development unless he consciously played down non-Western technology. In fact, the only quote on Chinese technology in Klemm's book is from the *Guan yin zi*, the work of a Daoist mystic of the eighth century AD: Klemm used it to prove why the alleged religiously colored oriental rejection of the world in China could not have provided a stimulus for the emergence of science and technology in that country.

This distorting Eurocentric perspective continued to hold sway even over the more standard (five volume) *A History of Technology* edited by Charles Singer, Holmyard and Hall. The first volume of this work appeared in the same year as Joseph Needham's *Science and Civilisation in China*, and the editors themselves acknowledged that up to the period of the Middle Ages in Europe, China had the most sophisticated fund of technological expertise. Three of the Singer volumes dealt with preindustrial technology, where logically China (and India) should have been given major space and Western technological development would have appeared in proper perspective in the nature of an appendix. However, Chinese, Indian, and other technologies were ignored and Western technology made the focus of the exercise.

In addition to manifesting such ignorance of non-Western science and technology, these histories suffered from another methodological limitation: they restricted themselves to a record of artifacts and machines disembodied from the latter's social and cultural contexts. The problem was eventually recognized by some Western scholars themselves.

These histories are evidence that the western scholars associated with them proved incapable of stepping out of their cultural cages, either knowingly or involuntarily. Either way, this eroded the credibility of their work as it exhibited both their lack of objectivity and their general incompetence when called upon to deal with societies other than theirs.

They show that our dominant descriptive and evaluatory ideas of technology and culture both in the Western and non-Western world have been formulated over the past couple of centuries with reference to the West's experience of these phenomena. Concepts and categories reflected from a limited area of human experience have been indiscriminately used to explain and assess the rest of the world.

New frameworks are therefore inevitable. We are in the posttraditional, postcolonial, and postmodern age. But unless the outmoded intellectual environment that engendered this subjective and tunnel-visioned output is rigorously dissected, analyzed, and then jettisoned, the new frameworks needed for the alternative histories and encyclopaedias intending to take their place are in danger of turning into copies of the old.

There are two preliminary aspects of this intellectual mal-development that need elucidation. First, there is the perception of humankind as *homo faber*, a tool-making animal, which is basically a reflection of fairly recent Western experience with the machine. Fascinated by the bewildering profusion of tools and machines, Western historians began to look at the ability to produce these as a special field with its own history and set out to create a distinct species of man in the image of *homo faber*. This scholarly creation had its repercussions in encouraging the overestimation of the singularity or uniqueness of Western culture in comparison with others (although all cultures are unique and incommensurate). The elaborate, embarrassing exercise in culture-narcissism soon became routine since it was not to be challenged for nearly a century. (It is important to point out that the *homo faber* idea is quite recent to humankind: it is consistently absent in not just other cultures, but even within a large part of the West itself.)

For instance, it was taken for granted that the system of production that got generated in the last century and a half in the West was the only one with any significance simply because in the light of the present – and to all appearances – it had apparently emerged as the dominant one. Therefore, its past was the only one worth considering. This notion was in turn bolstered by another: a self-generating model of technological development in which the historian attempted to trace the evolution of modern science and technology by working backward to the experiences and ways of thinking characteristic of Mediterranean antiquity. Thus the roots of modern technology were shown to be exclusively founded on the work of Greek and Roman thinkers, mathematicians, engineers, and observers of nature with no input from any other culture areas or people.

This brings us to the second aspect we have alluded to above, and this concerns the relationship between knowledge and power and the impact of this on interpretations of technology and culture. Throughout history, knowledge has generally remained closely linked with interests. Even when encyclopaedias, for instance, have traditionally sold themselves on the Francis Bacon principle that "knowledge is power", they too have continued to reflect an undeclared, equally influential, political principle – that "power is knowledge".

The intrusion of Europeans into non-European societies and the gradual establishing of political dominance and inequality between societies stimulated the inauguration of a new discourse about such societies. Political dominance came to be as routinely and unabashedly expressed in the form of knowledge as it was through the barrel of guns. Edward Said has already written on the invention of the discourse on "Orientalism" and its direct political uses. But there are less controversial discourses that have had even larger repercussions only now being acknowledged. As a result, much academic knowledge in the Western world about the non-Western world, particularly the latter's technology traditions, remains not only distorted or contaminated by the ethnic concerns, goals, theories, obsessions, and peculiar assumptions of Western scholars and universities; it is still largely defined, legitimized, and decided by them irrespective of whether there is any concurrence from the non-Western world.

The combination of these two aspects proved deadly: the emerging conception of Western man alone as *homo faber*, once it took firm roots within the situation of political dominance, rendered any appreciation of technique elsewhere – technique not necessarily reflected only in tools or machines – difficult and often impossible. In fact, the combination helped inaugurate its very own dark age. For it generated among Western (and not a few non-Western) scholars several major assumptions concerning technology and culture. We shall discuss three of these.

The first emerged in relation to Western man's attitude toward the past, particularly with regard to preindustrial technology. *Homo faber* exercised his new found power over the past by deriding it: this is reflected in the rewriting of history from today's perspective in which the past is seen as mere prelude to the present. Earlier technological innovations are considered primitive precursors of later developments. Here we have a good example of the parochialism of the modern/Western mind as it proceeds to take experiences of technology and culture exclusive not just to the late twentieth and early twenty-first centuries but to extremely small segments of the world population and makes these the basis for investigating, analyzing, assessing, and judging the general activities of human societies over hundreds of years. This was the case even when such societies were not so technologically enamored, dependent, or controlled as some of them seem to be now.

The second assumption relates to humankind's so-called unique propensities for technology when compared with that of the animal world, an uncritical theory best summed up in a single word: speciesism. After deciding on the issue of the comparative technological competence of all living species in its own favor, the West came to the conclusion that the rest of creation, because inferior, was expendable if so required to further its own scheme of things.

But it is the third assumption that concerns us most seriously here: it is the idea that Western man can be equally distinguished from non-Western societies as well on the ground that the latter, like the animal and other "lower" species, also lacked technological development as it emerged in the West.

This idea was appropriately reflected in academia in the emergence of two new sciences: the discipline of sociology, which focused on so-called advanced societies and their flair for technology; and the subject of anthropology which occupied itself with non-Western cultures, limited to primitive or preindustrial tools. Anthropology's political origins have been blandly asserted by Claude Levi-Strauss in his controversial Smithsonian lecture:

> Anthropology is not a dispassionate science like astronomy, which springs from the contemplation of things at a distance. It is the outcome of a historical process which has made the larger part of mankind subservient to the other, and during which millions of innocent human beings have had their resources plundered and their institutions and beliefs destroyed, whilst they themselves were ruthlessly killed, thrown into bondage, and contaminated by diseases they were unable to resist. Anthropology is daughter to this era of violence: its capacity to assess more objectively the facts pertaining to the human condition reflects, on the epistemological level, a state of affairs in which one part of mankind treated the other as an object.

It is within such an imperialist context that the histories and technological experience of non-Western societies could be written off or ignored: the latter, after all, were conquered peoples. When technology is seen through an anthropological prism, the emerging picture is bound to be far removed in character from a scenario that emerges from a sociological perspective. What is more, it is bound to be even more far removed from reality itself.

Some impression of that reality is discernible in the period before political dominance began to corrupt the objectivity of knowledge. Before the so-called "voyages of discovery," though non-Europeans were conceived as fantastic, wild, opulent, even monstrous, they were rarely considered inferior or backward; and even the actual European encounter with the scientific, technologic and medical traditions of non-Western societies was different from what eventually became the stuff of politically directed myths. In fact, from the day that the Portuguese mariner Vasco da Gama landed in India until almost three centuries later, Asia had a larger and more powerful impact on Europe than is normally recognized. Donald Lach has appropriately titled the first volume in his *Asia in the Making of Europe* "The Century of Wonder". It was not without reason that an Englishman of the time addressed the Indian Emperor by describing himself as "the smallest particle of sand, John Russel, President of the East India Company with his forehead at command rubbed on the ground." Nor can we forget that the first presents offered by da Gama to the King of Calicut included some striped cloth, hats, strings of coral beads, wash basins and jars of oil and honey. The king's officers naturally found them laughable.

It would take a few more decades before the Europeans landing in the Indian subcontinent would notice anything beyond gold and spices. But by 1720 and for a period of up to a 100 years, a new category of observers came visiting, some from newly formed learned societies in England. Their detailed reports were a result of the European quest for useful knowledge in different fields.

In his pioneering volume, *Indian Science and Technology in the Eighteenth Century*, the Indian historian Dharampal includes several accounts from these observers which describe among others the Indian techniques of inoculation against smallpox and plastic surgery. (While the first was eventually banned by the English, the latter was learnt, adopted, and developed.) The accounts also document Indian processes like the making of ice, mortar, and waterproofing for the bottoms of ships; water mills, agricultural implements like the drill plough, water harvesting and irrigation works, and the manufacture of iron and of a special steel called *wootz*.

More techniques (like those involved, for instance, in the manufacture of Indian textiles) are described in *DeColonizing History* (Alvares 1991) and *Science and Technology in Indian Culture* (Rahman 1984). But even this documentation, impressive as it is, is now recognized to be but the tip of the proverbial iceberg.

The Chinese, like the Indians at Calicut, had a similar experience with an embassy and its gifts from London. The edict of Qian Long to the embassy is worth quoting: "There is nothing we lack, as your principal envoy and others have themselves observed. We have never set much store on strange or ingenious objects, nor do we need any of your country's manufactures" (Fairbank 1971).

Immediately after the encounter, the graph of European reaction rises with esteem and wonder; and then, as political conquest and overlordship increase, the graph alters course and begins to record increasing denigration. A remarkable transformation of image thus takes place as the political relationship between Europe and non-European societies changes to the advantage of the former, rendering the Europeanization of the world picture almost an act of divine will.

By 1850, political dominance over the non-Western world was clearly installing distorted ideas not only about that part of the world but rebounding to distort Western man's image of himself as well. Already by 1835, for instance, the British had acquired a flattering notion of their own civilization (Victorian England was seen to be at the top of the pyramid of civilization) and a thorough-going contempt for Asia.

This contempt finds expression in the famous Minute of Lord Babington Macaulay:

> I have never found one amongst them (the orientalists) who could deny that a single shelf of a good European library was worth the whole native literature of India and Arabia… It is, I believe, no exaggeration to say that all the historical information which has been collected from all the books written in the Sanskrit language is less valuable than what may be found in the most paltry abridgment used at preparatory schools in England. In every branch of physical or moral philosophy the relative position of the two nations is nearly the same.

Dharampal has produced an interesting record of these assessments of science and technology in India among Western observers as the relationship between India and Britain changed to Britain's advantage.

Regarding the question of Indian astronomy, he discusses the case of Prof. John Playfair, Professor of Mathematics at the University of Edinburgh and an academician of distinction. Playfair studied the accumulated European information then available on Indian astronomy and arrived at the conclusion that the Indian astronomical observations pertaining to the period 3102 years BCE appeared to be correct in every text. This accuracy could only have been achieved either through complex astronomical calculations by the Indians or by direct observation in the year 3102 BCE. Playfair chose the latter. Opting for the former would have meant admitting that "there had arisen a Newton among Brahmins to discover that universal principle which connects, not only the most distant regions of space, but the most remote periods of duration, and a De La Grange, to trace, through the immensity of both its most subtle and complicated operations."

Similar attitudes prevailed concerning the knowledge of how Indians produced *wootz*. Heath, founder of the Indian Iron and Steel Company and later prominently connected with the development of the steel industry in Sheffield, wrote "… iron is converted into case steel by the natives of India, in two hours and a half, with an application of heat that in this country, would be considered quite inadequate to produce such an effect; while at Sheffield it requires at least four hours to melt blistered steel in wind-furnaces of the best construction, although the crucibles in which the steel is melted, are at a white heat when the metal is put into them, and in the Indian process, the crucibles are put into the furnace quite cold."

However, Health would not admit that the Indian practice was based on knowledge "of the theory of operations," simply because "the theory of it can only be explained by the lights of modern chemistry."

By the beginning of this century, the Western mind had already convinced itself that Western science and philosophy were the only approach to metaphysical truth ever attained by the human species and that the Christian religion provided wisdom and insight incumbent on all people everywhere to believe.

The result is reflected in the output of academia: a "history of art" turned out to be nothing but a history of European art and a "history of ethics" a history of Western ethics. While European music was music, everything else remained mere anthropology. The contemporary evaluation of human activity in the West as compared with the non-Western world was unabashedly provided by the late Jacob Bronowski in the Ascent of Man in words almost echoing Macaulay in 1837:

> We have to understand that the world can only be grasped by action, not by contemplation. The hand is more important than the eye. We are not one of those resigned, contemplative civilizations of the Far East or the Middle Ages, that believed that the world has only to be seen and thought about and who practiced no science in the form that is characteristic for us. We are active; and indeed we know, as something more than a symbolic accident in the evolution of man, that it is the hand that drives the subsequent evolution of the brain. We find tools today made by man before he became man. Benjamin Franklin in 1778 called man a 'tool-making animal' and that is right.

Now, there were obviously perverse consequences of such a view: scholars in several non-Western societies, schooled in an educational system imposed on their societies through the colonial establishment, readily incorporated similar ideas about their own histories. In an article in *Nature* 35 years ago, Joseph Needham had to chide a native scholar of Thailand for claiming that his own people had not made any contribution to science despite compelling evidence to the contrary. Nevertheless, the colonization project succeeded in convincing many non-European intellectuals and scholars that only the West was active. They facilely accepted the idea that activity per se was desirable compared to judicious or necessary activity; that only the West was capable of thinking in the abstract sense. If this opinion were carried to its logical conclusion, it would appear that if the rest of humankind had survived for hundreds of years, this must be due to some form of manna falling providentially from the heavens.

The damage done by these years of extremely ideological scholarship and a ruinous ethnocentrism to the history of technology was bad enough. Predictably, the impression of an empty technological wilderness invented by Western scholarship about non-Western societies had a parallel, simultaneous, destructive impact on the assessment of their cultures as well. So insidious was the nature of this outrageous assumption regarding Western and non-Western abilities, that even Joseph Needham, Mark Elwin, Abdur Rahman and a host of other scholars participated in pointless debates which often took it for granted. One major debate, for example, focused on why China (and India) did not produce either modern science or an industrial revolution on the European pattern, especially since Chinese technology had already reached a level of sophistication not yet attained in any other part of the world as late as the fifteenth century.

Attempted answers compared and contrasted the internal conditions within Chinese society with those within Europe; the argument eventually succeeded in establishing the conclusion that no scientific or industrial revolution occurred in China because the social conditions in China were not the same as those within Europe. Thereafter, a host of cultural and social factors were dragged out of context and labeled probable "obstacles" either to the development of technology or modern science.

A critique of the three assumptions we have surveyed above therefore becomes compelling and inevitable, if we are to eschew their myriad fallacies in future. We shall take each in turn.

The idea that the past was merely a prelude, and a primitive one at that, may come naturally to anyone who has begun to feel that the present era of technical change is inevitable. Yet future societies may assess their past (our today) basing themselves on values other than those celebrating mere technical change. Already mindless technical change and built-in technological obsolescence have been assaulted by several global thinkers on the ground of ecological unsustainability and resource scarcity. It would also be wrong to think that because man did not have technology as he now does, he was necessarily impoverished. If there is anything the past gives us it is this positive impression of survival in all kinds of environmental scenarios. There is also evidence of more widely dispersed creativity when man was not submerged by technology than there is today. In many areas of human experience, we are yet to match even the technological achievements of the past which were driven by values other than mere complexity for its own sake or profit.

A similar argument may be used against the assumption that humankind is the only tool-making species there is. Several naturalists and ethologists have documented the diversity of nature's schemes at fabrication; most notably, Felix Paturi in his *Nature, Mother of Invention* and Karl von Frisch in *Animal Architecture*. Scholars like Lewis Mumford have gone further in stating quite bluntly that in their expression of certain technical abilities other species have for long been more knowledgeable than man.

> Insects, birds and animals, for example, have made far more radical innovations in the fabrication of containers, with their intricate nests and bowers, their geometric beehives, their urbanoid anthills, and termitaries, their beaver lodges, than man's ancestors had achieved in the making of tools until the emergence of homo sapiens. In short, if technical proficiency alone were sufficient to identify and foster intelligence, man was for long a dullard, compared with many other species.

Niko Tinbergen, another ethologist, after years of close observation of other species, has come to the following conclusion: "It was said that (1) animals cannot learn; (2) animals cannot conceptualize; (3) cannot plan ahead; (4) cannot use, much less make tools; (5) it was said they have no language; (6) they cannot count; (7) they lack artistic sense; and (8) they lack all ethical sense." All of these statements, says Tinbergen, are untrue.

It cannot be said therefore that, in contrast with other species, humankind alone is a tool-maker. Thus the attempt to distinguish man from other living species because of his tool-making capacity is now seen to be a result of limited knowledge and unwarranted assumption of qualitative discontinuities between human beings and other species. It will also be useful to recall here that the ability to fabricate and organize is not a singular human trait – it is an intrinsic feature of nature since nature can exist only in a given form, whether at its most primary constituents at the subatomic level or even at the level of crystalline structures or the multiple tiers of a primary forest.

However, it is the third assumption – concerning the West's genius for technology and the rest of the world's incompetence in the same department – that contains the greatest mythological component of them all.

As we shall presently see, such an assumption has not only no historical basis, it is in fact contrary to historical and even to contemporary evidence. As for the gift of Greek rationality, suffice it to say that for 2,000 years it gave no technological advantage to those who had it over those who did not. On the contrary, major scientific concepts, technological artifacts, tools, and instruments emerged in cultures that had nothing to do with either Greece or Rome.

The other problem with this assumption is it cannot even cope with the long established view that the science and technology traditions of most societies, particularly so of the West, are in significant ways mixed traditions. Even the little that we know about it indicates that the cross-cultural borrowing of technics and technology is impressive. Thus a very large number of critical inventions from both India and China helped fill significant gaps in the technological development of the West. A simple example from Francis Bacon's work will suffice to illustrate this point. He wrote:

> It is well to observe the force and virtue and consequences of discoveries. These are to be seen nowhere more conspicuously than in those three which were unknown to the ancients, and of which the origin, though recent, is obscure and inglorious; namely, printing, gunpowder, and the magnet. For these three have changed the whole face and state of things throughout the world, the first in literature, the second in warfare, and the third in navigation; whence have followed innumerable changes; inasmuch that no empire, no sect, no star, seems to have exerted greater power and influence in human affairs than these mechanical discoveries.

Now all these three mechanical discoveries were Chinese. Yet here again Western scholars have found it hard to acknowledge their origin. Borrowing of techniques from India is easily documented as well.

The documentation of technology in other cultures is only beginning. For example, it was only in 1974 that Sang Woon Jeon's *Science and Technology in Korea* appeared. There is as yet no major record of technology in Africa or South America though there is now available a large volume of documented evidence that both areas were rich in tools and techniques, from metallurgy to textiles.

In India, the other large storehouse of useful and appropriate tools (some still in productive use), the most extensive documentation of technology has only recently commenced, sparked in part by Dharampal's *Indian Science and Technology in the Eighteenth Century* and the work of scholars like Abdur Rahman.

The immediate impact of these reinvigorated investigations, stimulated largely by political independence, is a fresh debate over the issue of technology and culture: the old assumption of one technology and one culture in which others are seen to make a few, presumably inconsequential, contributions, is in tatters. Whatever its own pretensions to be the only viable culture, the West is finally being seen by non-Western societies as only one among several: a certain balance between cultures gets restored even though economic inequality persists. In fact, in some cases the pendulum has swung to the other side with cultures unabashedly resuming their traditions. There has naturally been a reverberation in the climate of ideas.

Changes in perception of this kind have already come about in other academic disciplines. To cite just one example, world histories were once written as if Europe were the center of the planet, if not the cosmos. There has been progress since: Geoffrey Barraclough and Leon Stavrianos, for instance, have both succeeded in producing comprehensive histories which avoid the older Eurocentric perspectives.

But even assuming we are able to produce, culture by culture, a fairly objective and comprehensive record of science, technology, and medicine, we would still be uncomfortably close to the pet obsession and perception of the present epoch. If there is anything the recent past has shown us, it is that we can be all too zealous judges in our own cause. We continue to celebrate uncritically our technological feats even when we know that the principal criterion of success for any species (and the human species is no exception) is primarily its ability to survive.

Therefore, it may be best not to get trapped in the debates on what is basically a subhistory: the history of slave-machines or automation or the recent machine-propensity of some cultures. After all, the *homo faber* concept is itself a distorted reflection of the natural endowments of the human species, an example of reductionist thinking. We know now that reductionism readily distorts knowledge, often pauperizes it, but rarely enhances it.

What is required in the circumstances then is a paradigm shift. I would like to suggest this can be achieved by replacing the heavily loaded term "technology" (too close identified with externalized objects) with the more neutral word, "technique." Technique has a larger ambit than technology and does not necessarily express itself only in the form of tools or artifacts. For the moment, we may define it briefly as every culture's distinct means of achieving its purposes. The natural propensity of human beings is to rely on technique, not technology, for while it has been proven that we can survive without technology, we cannot survive without technique.

Thus there can be no technique without culture, no culture without technique. An investigation into a culture's techniques is bound to be considerably more difficult than the recording of a culture's artifacts. The important gain here would be that we would begin with a more democratic assumption: that there is no culture without a system of techniques. Such a postulate would inoculate us effectively against methodological, ethnocentric, and other fatal flaws the *homo faber* concept was both parent and heir to. It would nip in the bud any undesirable future forays into cultural narcissism or ethnocentric discourse.

If this is indeed so, the more logical assumption would be that every culture has relied on a corresponding system of techniques that has guaranteed survival. Understood in this way, it makes far better sense to talk of Western technique (even though today largely expressed in the form of technology), or African, Indian, Chinese, Maya, or Arabic techniques of survival (in which technology may not be given that importance for fairly valid reasons). But even a relatively low importance given to technology could never mean a poverty of technique. The idea that the human species is technique-natured could be empirically falsified if a human society could be found that lacked technique – and not just machines or artifacts.

Technique, then, is nothing but the permanent but dynamic expression of an individual culture. Cultures can only express themselves or survive through technique: the alternative is chaos. Nonhuman species may be guided in the exercise of technique by inflexible inborn patterns of behavior. But the human world is as rigorously bound by the controls imposed by the symbolic universe that emerged as a substitute for weakened instinctual patterns. Myth, for instance, is technique. Interaction with (or manipulation of) nature may take place either through myth-making, scientific construction, and myriad other ways. All are expressions of the symbolic universe human beings inherit because they are human beings.

Thus we share the necessity of functioning through technique – not just through tools – with other living species – from the mammoth geobiological processes of Gaia to the cross-pollination of the rice plant to species of bird and animals, some of which, like the bower bird, are more prone to technology than others. Thus the so-called potter-wasp is known for its technique in constructing what we human beings culturally recognize as pots: however, the small vessels are the conclusion of technique: without it, there would be no "pot", no propagation and, therefore, no survival.

This will also explain why so-called primitive societies are often more complex in their socio-cultural arrangements – their rich fund of botanical knowledge, slash-and-burn techniques, elaborate myths are as much an expression of technique – than modern societies.

Our new paradigm – based on a thorough-going analysis of technique – will enable us to concentrate more effectively on those aspects of human experience in non-Western societies where there may be appropriate development of technology (as in India and China) but a superabundance yet of technique. A large number of these, particularly in India or in the Islamic cultures, may be located squarely within the domain of the sacred. They would be unintelligible outside such a framework of understanding.

We shall also observe in such societies that even where there is sophisticated technology, it retains an unobtrusive (not invasive) character. This can be seen from the merged outlines of Arab architecture to the irrigation works of South India or Sri Lanka.

An encyclopaedia of non-Western science, technology, and medicine may restrict its scheme to a bare description of the evolution of machines or artifacts incompetently covered by earlier conventional Western works, but it must do so guided by the background of the larger canvas of technique. Here the scholar will eventually examine theories of language in the same detailed manner as he would the culture and preparation of food or the control of breath – all extremely detailed sciences in India and China; he would examine irrigation and animal husbandry techniques, the domestication of cultivars of crop plants, record the elaborate knowledge of plants and of the human body, and seek to understand theories of cosmic phenomena and of the behavior of annual events like the monsoons.

The aim of the historian is to describe the nature of this individual system and not place it within a hierarchical ordering of societies. His task is to document this immense richness, not endeavor to swamp and drive it into oblivion on the questionable assumption that Western technology is the only direction that human technique will take. The growing anxiety over Western technology is closely associated with the threat it is perceived to pose to the fate of the planet and to survival. We may have to examine its history clinically to diagnose why it has generated the kind of problems it poses for humankind. Here, only a proper study of technique and culture within non-Western societies (and not as Forbes hoped, the event of Easter) will bring some balance and provide urgent clues to the origins of what Jamal-ud-din described as the illness of occidentosis, the plague of the West.

See also: ►East and West, ►Colonialism and Science, ►Technology, ►Ethnobotany

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Technology and Environment

ARNOLD PACEY

The development of technology has usually been socially determined, changing in direction as different social formations have emerged. For example, there are important distinctions to be made between, first, small communities of farmers or dispersed groups of hunters with technologies outstanding chiefly for their adaptation to local *environments*; second, the larger kingdoms and empires, whose technology tended to be *engineering-centred*; and third, trading communities and merchants or entrepreneurs with *production-centred* technologies.

An initial problem in discussing technologies of the first kind is nomenclature. J. S. Weiner, who has discussed the remarkable protective clothing developed by the Inuit for life in the Arctic, has described these people as "the great pioneers of micro-climatological bioengineering”. This tribute to the control of body heat loss achieved by Inuit clothing is well deserved but places the skills of Arctic people within the wrong frame of reference. Their technology was environment-centred, not engineering-centred. On the one hand, they were adapting to a very demanding environment; on the other, they were making very efficient use of environmental resources. Thus, the animals hunted for meat were also a source of oil for lamps, bone for making needles and other tools, and the skins, intestines, and fibres from which clothing was made.

Archaeological evidence suggests that the invention of tailored skin clothing adequate to enable people to winter in the Arctic was accomplished in Siberia around 2000 BCE. After that, it was several centuries before oil lamps, houses built of snow, and dog sleds were developed by the people of the Dorset Culture, based on Baffin Island. Later still, improved boats and harpoons were developed by the Alaskan Inuit.

All these inventions, quite clearly, were the work of small, dispersed groups without centralized organization, and all were responses to an exacting environment. Perhaps what we ought also to remember is that for the Inuit, as for most non-Western peoples, the environment was endowed with personal and spiritual meanings and with magical qualities. It was not merely the object of detached, if concerned, analysis that it has become for most Westerners. Thus, their technology was based on an organic worldview.

The same points can be made about peoples inhabiting other environments, such as rainforests, deserts, steppes, or coastal and island situations. The efficiency with which resources were used by such people is illustrated by the estimate that in 1500 CE the Amazon basin supported a somewhat larger population than it did in 1990, yet without the extent of destruction of forest and fishery resources now taking place. Fruits, nuts, leaves, seeds, and roots were gathered for use as food and medicine. Fish and animals were caught, often using poison tipped spears, but with less ecological disturbance.

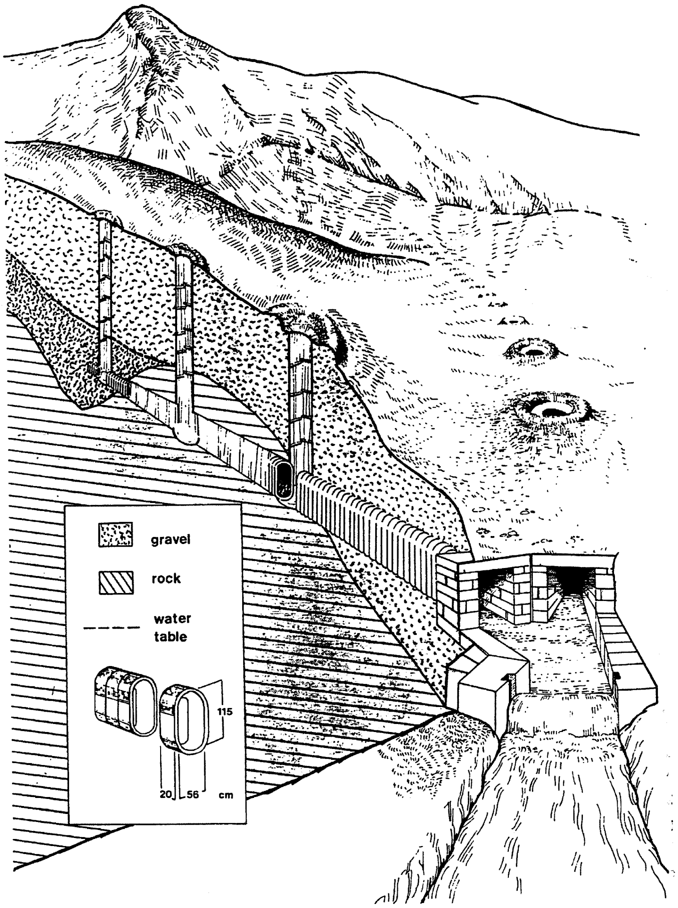
In some rainforests, notably in Central America as well as in Asia and Africa, people developed a form of agriculture in which a great variety of crops was raised while extensive tree cover was retained. Cereals such as corn in the Americas or rice in Southeast Asia were grown in forest glades with shade-tolerant vegetables under trees. Those trees that were left unfelled or were newly planted would be selected according to whether they produced fruit, nuts, timber, fodder, or *materia medica*. Thus, an artificial rainforest was formed in a system often referred to as forest farming, forest interculture, layered gardening or, more recently, agroforestry. The key point – whatever the name – is that there would always be tree cover, and usually other vegetation, to protect the soil from erosion and to retain plant nutrients. By contrast, where rainforest is cleared for conventional western style agriculture, soils become degraded very rapidly.

In Africa, rainforest crop production became widespread only after the banana and Asian yam were introduced on the east coast by Indonesian traders and colonists around 400–500 CE. In quite a short space of time, these crops were adopted by many gardeners across the continent, enabling populations in forested areas to increase considerably. In Central America, archaeologists have now shown that the Maya culture used forest farming with high yielding nut trees and manioc (cassava) as major crops around 600–900 CE.

Other environment-centred technologies were those of people living in hot, dry, and semi-desert conditions who evolved sophisticated water conservation techniques. Some of these made use of small structures, such as check dams in gullies and spreader dikes on flatter ground – for example, in northern Mexico and Arizona – or else stone lines on contours (in the African Sahel). Others practiced the careful planning of fields in relation to rainwater catchment areas, and the construction of bunds (embankments or dikes) to channel water and hold it on the land. Among the most elaborate rainwater harvesting systems of this kind were those of Nabataean farmers in the Negev Desert in Israel from about 200 BCE, and comparable systems in Morocco and elsewhere in North Africa. Small dams, river diversions, and the Persian *qanat* (wells linked by a tunnel; Fig. 1) were other means of providing irrigation water to crops on a small scale.

Consideration of environment-centred techniques such as these offers a distinct perspective on early technology quite unlike the conventional view based on the materials from which tools were made, namely, stone, bronze, and iron. That view seeks to discover a pattern of tool use and metalworking skill common to all human societies, and ignores the environmental particularism emphasized here. It parallels the modern assumption that the principles of technology are independent of cultural values and underestimates the different ways in which human societies explored the varying surroundings in which they lived. By contrast, a perspective based on environmental adaptation allows one to recognize the extraordinary sophistication of some peoples who nominally remained in the “Stone Age” even in the early twentieth century, including the Inuit and some rainforest communities.

Viewed from another angle, however, the Neolithic period in the later Stone Age does seem to have been a time of particularly important innovation, at least for western Asia. It is associated with the first domestication of crops and livestock, and hence the invention of agriculture, probably associated with the earliest used of some of the water conservation techniques previously discussed. Complementing these innovations were



Technology and Environment. Fig. 1 Two *qanat* tunnels in a typical landscape, where rainwater running off mountains replenishes groundwater beneath the sand and gravel of the lower slopes (water-bearing gravel is shown darker than the dry gravel layer above). The ground penetrated by one of the *qanats* is shown in cut-away section to demonstrate how the tunnel gives access to water trapped by impervious rock. The section also shows how the tunnel is lined with earthenware rings when passing through sand or gravel layers which might otherwise cave in. *Qanat* tunnels were excavated from the bottoms of a series of well shafts, with the "mother well" at the upstream end dug first to prove the existence of water. The tunnels were sometimes several kilometres long with their route evident on the surface from the line of well shafts, as on the right of the picture (illustration by Hazel Cotterell based on sketches by Arnold Pacey; reproduced from Pacey 1990: 86).

others, such as pottery (and soon after, the potter's wheel), grain milling, tool-making, and textiles (with the looms on which they were woven). Many of these innovations relate to the domestic sphere of life, and it is likely, therefore, that many of the inventors concerned were women.

It would be a mistake, however, to assume that the invention of agriculture, the domestication of plants, and the appearance of pottery or textiles were unique events, each occurring only once in human history, in one part of Asia and then diffusing to other regions. Independent inventions undoubtedly occurred, just as different crops were domesticated in various places and at different times. For example, about 1500 BCE, corn (i.e. maize) and pottery were both known in Mexico, but not in Peru, where beans and peppers were cultivated. Thus, the two cultures may have developed agriculture independently of one another. Moreover, some plants were still being newly domesticated in the twentieth century, for one reaction to deforestation in Africa has been to cultivate a number of fruits and vegetables that people had collected from the wild until the loss of forest cover threatened their existence. Reports from Kenya show how modern gardeners, usually women, have selected from wild varieties and have produced strains adapted for garden conditions.

Engineering-centred technologies developed in a very different context. They were characteristic mainly of kingdoms or empires whose labour resources and administration made large-scale construction works possible. One view of the origins of engineering is that once agriculture was established, irrigation became necessary in many of the warm, dry countries of western and southern Asia to produce sufficient food for growing populations. The dams and canal systems necessary for irrigation could not have been constructed, it is argued, without recruiting a large labour force, and that in turn could not have been done except in centrally organized kingdoms. In this view, the need for irrigation canals and other hydraulic works dictated the formation of centralized government administrations with the coercive power and management skills needed to organize large-scale construction works.

This theory about how hydraulic civilizations evolved does not apply everywhere, however, since empirical evidence shows that in many areas where irrigation was practiced, farmers did the essential earth moving and engineering work themselves, or with their neighbours through local systems of cooperation, but without central organization. This seems to be true for rice culture in China, according to Francesca Bray. Some of the biggest centrally organized engineering schemes prior to 605 CE, involving thousands of labourers, were not for irrigation but for construction of transport canals for carrying grain to the capital. However, flood control and irrigation in North China did depend on large-scale works, so the evidence is not clear-cut.

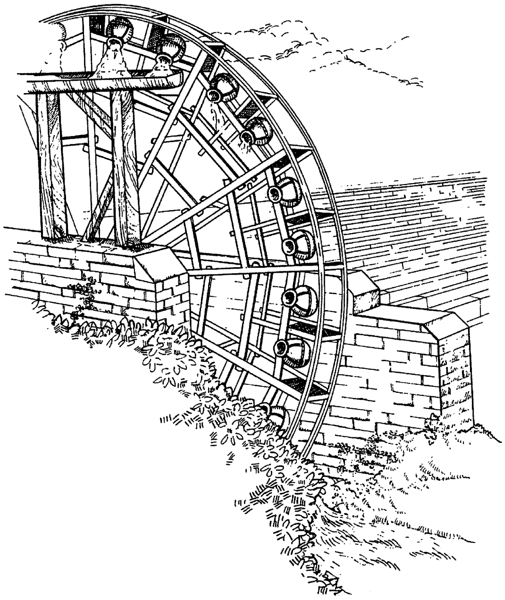
In Mesopotamia and Egypt, much early irrigation was also on a small scale, dependent on manually operated water-raising devices such as the *shaduf* (a device consisting of a long suspended pole weighted at one end and having a bucket at the other end). The type of crops grown and the seasons of cultivation meant that there were fewer water requirements in early agriculture than after the agricultural revolution of the Islamic period (after 700 CE), when crops that demanded more water (including rice) were more widely grown. In Mesopotamia, large-scale works were needed at an early date, but in most places it is hard to argue that the requirements of hydraulic management were sufficiently exacting to determine the development of centrally organized states. On the contrary, the prior existence of centralized political power made possible a wide range of construction programs that included fortifications, monuments, and temples, as well as hydraulic works, and it is impossible to say which kind of engineering came first. One of the earliest sites to provide evidence is Jericho, where defensive walls, but also big water tanks, have been found dating from before 6000 BCE. The pyramids of Egypt were among the largest construction projects ever conceived when they were begun about 2600 BCE. But a comparable amount of labour may have gone into embankments and canals built at about the same time for flood control and irrigation by the Sumerians in Mesopotamia. Thus, the evidence does not give a clear picture of hydraulic requirements, rather than other construction works, forcing the pace in either administration or engineering.

That brings us to a second hypothesis about how engineering-centred technologies evolved, suggested by Lewis Mumford and some like-minded commentators. This is the view that such technologies were related to the invention of warfare, for indeed, organized lethal warfare had to be invented, and this may have happened during the Neolithic age, possibly following the invention of agriculture. The reasoning here is that agriculture made possible denser populations within which social tensions were inevitable and from which large bodies of fighters could be recruited, while at the same time, agriculture produced the economic surplus needed to pay for arms and fortifications. It is suggested, also, that centralized governments and military institutions began to evolve about this time, and provided a model of how large bodies of people could be organized and supervised, not only in combat, but also in constructing fortifications – or dams, canals, and pyramids.

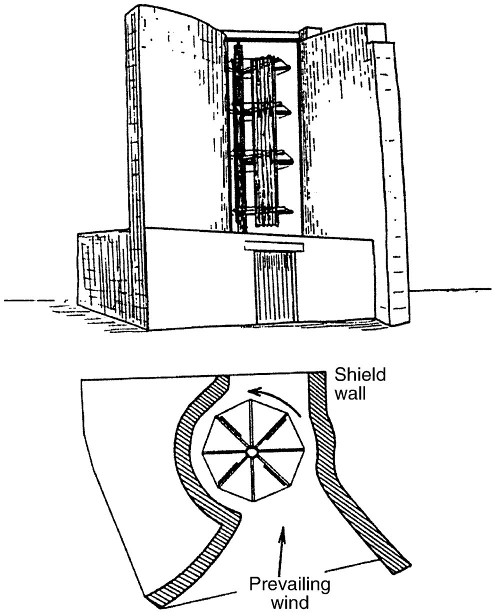
Needless to say, the development of warfare provided other stimuli to engineering-centred technology. Mechanized fighting may be said to have begun with the clumsy, four-wheeled Sumerian chariot of about 2400 BCE. The Hittites, whose empire overlapped Asia Minor and Syria, invented some of the first effective siege engines soon after. Horses were initially used mainly for drawing chariots, their full potential for warfare only emerging much later with the invention of the stirrup and its associated harness. This freed the rider's arms to use weapons while he remained securely in the saddle.

Engineering-centred technologies in ancient civilizations can appear to be focused very largely on large-scale hydraulic works and on military engineering. In addition, one bias in the western understanding of technology is a tendency to focus on the wheel, and on machines using wheels, such as the early chariots just mentioned. But wheels did not always mean progress. Wheeled vehicles were used in the North and West of Africa around 500 BCE, regularly crossing the Sahara Desert. Yet they went out of use later when the camel was introduced, because camels provided much more efficient means of transport in a region with sandy deserts and no paved roads. For parallel reasons, wheeled vehicles were not much used in southern Asia. In Central America, rollers and wheeled toys have been found, but in a region where there were no animals capable of pulling carts, little could be gained by developing such devices.

The potter's wheels (and later, lathes working on similar principles) were probably the first machines to use the wheel, around 3000 BCE. Much later, a basic water-powered corn mill evolved, with a vertical axle



Technology and Environment. Fig. 2 Water-raising wheel of the type known as the *noria*. This is an undershot water wheel, driven by the flow of water in the stream running underneath it. The jars tied to the rim fill from the stream and then empty into the trough at the high level (illustration by Hazel Cotterell; reproduced from Pacey 1990: 11).



Technology and Environment. Fig. 3 Persian-type windmill showing how shield walls were designed to funnel wind onto the sails, which rotated on a vertical shaft. The way the mill worked is most clearly seen from the plan (lower illustration). The perspective view shows how the shield walls of later mills formed a towering open structure built of sun-dried bricks with a small room containing the millstones underneath. The earliest mills seem to have been of different design with the millstones supported by the shield walls at the top of the structure (illustration by Arnold Pacey, based on photographs by Dick Day of a windmill in Afghanistan; reproduced from Pacey 1990: 12).

and propeller-like blades below the millstones. One view is that this was a Greek invention made about the time of Alexander the Great. Another view, however, is that it arose out of the Hittite tradition of engineering which had earlier pioneered so much military equipment. After the Hittite empire collapsed around 1200 BCE, some aspects of its culture survived in Syria, and itinerant craftsmen perhaps reached Mesopotamia and Iran. It was probably in one of these countries that vertical-axle water mills originated. Since the same type of mill appeared in China not long afterwards, one might reasonably look for its origins close to trade routes with China. A related invention of the same period was the water-raising wheel or *noria*, a basic water wheel with a horizontal axle and pots or buckets attached to its rim in which water could be raised (Fig. 2).

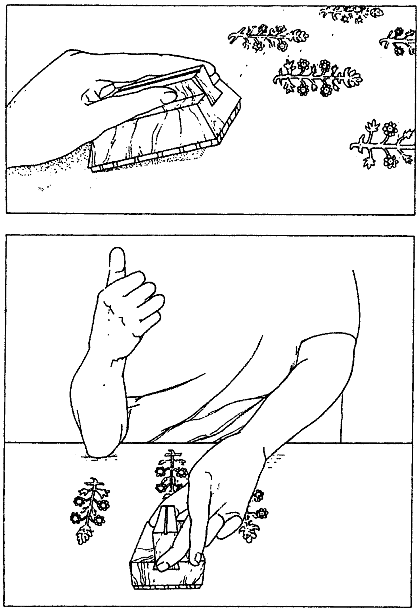
Some thousand years later, Iran was certainly where an early type of windmill was invented. It worked in much the same way as the vertical-axle water mill, though mounted in a tower with vents in the walls to catch the wind (Fig. 3).

In both Iran and Iraq extensive use was made of water wheels of several types, and some large dams were erected. Other uses of water power in this region around the year 1000 CE were in sugar cane crushing mills, fulling mills, and mills for preparing the pulp for papermaking. Paper manufacturing had been introduced at Baghdad in 794 CE, probably with the help of Chinese workmen, and water wheels were used to work hammers that made pulp from 950 CE.

Production-centred technologies can be said to include devices such as corn mills, or iron smelting, or the porcelain industry which developed in China. Other evidence of production technologies in China includes several inventions that first appeared there in the three or four centuries prior to 1250. They include spinning wheels, silk-winding machines, and water-powered mills for spinning and winding thread.

Much production of pottery and textiles would be carried on in a domestic context, but there were also instances of large-scale production, of which the most characteristic unit in South Asia was the *karkhana* of Mughal India, or the specialist porcelain factory in China. At one time 4,000 silk workers were employed in karkhanas in Delhi, some of them conscripted.

Production for purposes of trade had to be more flexibly organized and flourished most markedly where merchants could function independently. By 1700, India had become the world's greatest exporter of textiles, sending its cotton cloth to Europe, Africa,



Technology and Environment. Fig. 4 Indian technique for printing designs on cloth using a wooden block, applied by hand to transfer a mordant (rather than the dye itself) to the cloth. Mordants are chemical substances that made the cloth receptive to dye. First the wooden block carved with the flower pattern being printed is carefully placed in position (top), and then it is struck sharply with the right hand to transfer the mordant solution from the block to the cloth (illustration by Hazel Cotterell based on sketches by Arnold Pacey; reproduced from Pacey 1990: 85).

and many destinations in Asia. Both Indian and foreign merchants were involved, sometimes financed by the many Parsi and Gujarati bankers to be found in ports such as Surat.

It should not be thought, however, that proto-capitalist industrial organization was always favourable to the use of machines, water-powered or otherwise. The high quality of Indian textiles was achieved by painstaking handwork, as in the printing of designs on cloth (Fig. 4), and sometimes by a very fine division of labour. British observers noted that cotton cloth would sometimes be worked on by four people for every one employed on the same tasks in Europe. Thus the remarkably fine muslin produced in Bengal was the result of many detailed processes which would be simplified and reduced to a single operation in the West.

Indian cloth was also noted for the fastness and brilliance of the colours with which it was dyed, mostly using vegetable dyes such as indigo and madder. However, some inorganic substances were also needed as mordants, to help dyes bond with textile fibres and often modifying the colour, and this gave rise to a significant chemical industry. For example, the alum used in madder dyeing was produced in Rajasthan by processing broken shale tipped as waste around copper mines (Fig. 5). These chemical processes were operated on a substantial scale but using labour-intensive methods and minimal equipment. Merchants and banks had ample funds to invest in the textile trade, but because wages were low, there was little advantage in financing more productive equipment.

Technology and Environment. Fig. 5 Alum production in Rajasthan, India, about the year 1800 CE. Shale tips associated with copper mines provided the raw material and can be seen in the background on the right. Shale was steeped in water in rows of pots on the tips. The liquid was then brought to the boiling house seen to the left where some water was evaporated off and the pots left to stand. Blue crystals of copper sulphate formed and were removed. After decanting the liquid and boiling it again, saltpetre was added. The alum was formed by reaction of the saltpetre with aluminium salts in the solution, and crystallized at the bottom of the pots (illustration by Hazel Cotterell based on sketches by Arnold Pacey; reproduced from Pacey 1990: 122).

Technology is too often equated with engineering and hence with structures, machines, or equipment. However, a deeper understanding of technology in non-Western cultures demands awareness of subtleties in responses to the environment by which human survival was guaranteed in very varied conditions, and subtleties in the use of materials (such as dyes and mordants) by which high-quality production was achieved without machinery.

Thus while engineering-centred technologies that are easy to illustrate with pictures of machines are central to most people's image of what technology is about, a more fundamental view of technology must take account of responses to the environment that cannot easily be illustrated, such as rainwater harvesting or agroforestry where there are no machines to illustrate.

See also: ▶Ethnobotany, ▶Military Technology, ▶Gunpowder, ▶Paper and Papermaking, ▶Colonialism and Science, ▶*Qanat*, ▶East and West, ▶Western Dominance

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Technology in the Islamic World

DONALD R. HILL

Hydraulic engineering was the most important technology of medieval Islam. Irrigation schemes supported a thriving agriculture and such schemes involved the construction of canals and *qanats* (see below), dams and water-raising machines. At the other end of the chain, water power was needed to process the raw agricultural products. In this article, we will begin with a survey of hydraulic engineering which will give us an overview of many of the significant aspects of Islamic technology.

Following this, a brief summary of a few other technologies will help us to appreciate the richness and diversity of Islamic material culture. The brevity of this summary is because of limited space and should not mislead readers into thinking that these technologies were insignificant, either in the social life of Islam or in the history of technology.

In Egypt, basin irrigation was in general use. This consists of leveling large plots of land adjacent to a river or canal, and surrounding each plot by dikes. When the river reaches a certain level the dikes are breached, allowing the water to inundate the plots. It remains there until the fertile sediment has settled, whereupon the surplus is drained back into the watercourse.

The regime of the Nile, with the predictable arrival of the flood, made Egypt particularly suitable for basin irrigation. Elsewhere in the Islamic world, however, perennial irrigation was, and is, practiced extensively on all the major river systems. As the name implies, it consists of watering crops regularly throughout the growing season by leading the water into small channels which form a matrix over the field. Water from a main artery – a river or a major canal – is diverted into supply canals, then into smaller irrigation canals, and so on to the fields. In many cases the systems operate entirely by gravity flow, but water-raising machines were used to overcome obstacles such as high banks, whether they were natural or artificial. Perennial irrigation from wells, again using water-raising machines, is also extensively practiced in the Islamic world.

After the advent of Islam a number of existing systems were extended in order to cater for the needs of newly founded cities. Completely new systems were also constructed. In central Iraq the Muslims inherited the network constructed by their predecessors, the Sasānid dynasty of Persia. The major expansion occurred after the foundation of Baghdad in AD 762. The great Nahrawān canal, which left the east bank of the Tigris a short distance below Takrīt, was extended southward.

The rivers ʿUzaym and Diyāla, which discharge into the Nahrawān from the east, were dammed by the Muslim engineers to provide water for a huge irrigated area. Further south, to the west of the Shaṭṭ al-ʿArab, the city of Basra was founded in the seventh century. Originally it was simply an army encampment consisting of reed huts, but soon it grew into a great city which had no rival in Islam before the foundation of Baghdad. Gradually, in the last decades of the seventh and the first decades of the eighth centuries a vast network of canals was constructed to serve the demands of a thriving agriculture.

Other important systems were based upon the rivers in the province of Khurāsān, then much larger than the eastern Iranian province of the same name. Some of the most impressive networks were based upon the river Murghāb, upon which stands the city of Marv. In the tenth century the system was controlled by a specially appointed Amir who had 10,000 men under him, each with an appointed task. This Amir is said to have had more authority than the prefect of Marv. Other important schemes in the east were those centered on the cities of Bukhārāʾ and Samarqand and on the lower reaches of the Amu Darya (Oxus) river.

In Spain, the Muslims greatly extended the irrigation schemes that had been constructed by the Romans and Visigoths. Syrian irrigation technology – large contingents of the conquering armies were from Syria – was applied in Spain, where the climatic and hydraulic conditions of the rivers of the north were very similar to those in Syria. The irrigation systems, such as those along the Gudalquivir river and those in the province of Valencia, were the basis of the agricultural prosperity of Muslim Spain. Indeed, systems such as that in Valencia, basically unchanged since Islamic times, continue to serve the needs of the province to the present day.

A particular technique, originating in Armenia about the eighth century BCE, and still in widespread use in modern Iran, was the *qanat*, an almost horizontal underground conduit that conducts water from an aquifer to the place where it is needed. For the preparatory work an experienced surveyor carefully examines the alluvial fans, the terrestrial equivalent of a river delta formation, in the general location of the proposed *qanat*, looking for traces of seepage on the surface and often for a barely noticeable change in vegetation, before deciding where the trial well is to be dug. When a successful trial well has been excavated, it is now known as the mother well. The surveyor levels from this point to the outlet of the qanat, marking the positions and levels of the proposed ventilation shafts at 30–50 m intervals. These shafts also provide for excavation of the spoil. A skilled artisan (*muqannī*) then begins work with his assistants by driving the conduit into the alluvial fan, starting at the mouth. At first the conduit is an open channel, but it soon becomes a tunnel. Another team sinks ventilation shafts ahead of the tunnelers, and laborers haul up the spoil to the surface through these shafts by means of a windlass. The tunnel is about 1 m wide by 1.5 m high; in soft soil hoops of baked clay, oval in shape, have to be used as reinforcement. As the work nears the mother well, great care has to be taken in case a muqanni misjudges the distance and strikes the full well, in which case he might be swept away by the sudden flow.

The construction of canals, qanats, and other public works required the assistance of skilled surveyors. The earlier methods of leveling were rather slow and tedious. This involved stretching a string between two staffs divided into graduations and held vertically. A level was suspended to the center of the string. One type, for example, was an inverted isosceles triangular frame suspended by hooks to the string. Fixed to the center of the horizontal leg was a plumb line. One end of the string was moved up or down the staff until the plumb line passed through the inverted apex of the triangle, at which point the string was level. The difference in level between the two staffs was noted. In the eleventh century a level was introduced akin to our modern instrument but without, of course, any telescopic or electronic aids. A thin copper tube rotating on a circular plate that was suspended to a "gallows" was aimed horizontally on to a level staff. The reading gave the difference in level between the two points. The rises and falls along the route of the survey, summed algebraically, gave the level difference required. Triangulation, by which the heights and distances of objects, whether accessible or not, could be determined was usually carried out by the astrolabe. Quantity surveying methods were very similar to those in use today. The amount of excavation for a canal, for instance, was first calculated. Then, by applying known unit rates, the engineer worked out the number of excavators, laborers, foremen, and supervisors. From these results he prepared a Bill of Quantities which was used for measuring progress and paying the contractor.

The main purpose of dams was to divert water from rivers into irrigation systems. Our knowledge of Muslim dams comes from two sources: reports in the works of Muslim geographers, and the examination of Muslim dams which have survived to the present day. In the east, one of the most impressive dams, known as the Band-i-Amir, was built in 960 over the river Kūr in Iran, between Shirāz and Persepolis. As described by the tenth-century geographer al-Muqaddasī, it was used to irrigate 300 villages. At each side of the dam, downstream, were ten water-raising wheels and ten water mills, all given extra power by the head of water impounded behind the dam. The dam was constructed throughout of masonry blocks, and the joints were made of cement mortar strengthened with lead dowels. The dam still exists and it is not surprising, given the solidity of its construction, that it has had such a long and useful life.

Also in Iran, at Kebar, about 15 miles south of Qum, is a dam which is very important in the history of dam construction. Built in the thirteenth century, it is the first known example of the true arch dam. It did not depend for its resistance to water pressure on gravity but was built as an arch, its convexity pointing upstream, and its sides were anchored securely into the rocky sides of the gorge in which it was built. The forces were transferred to the abutments, and it was considerably more slender than a gravity dam across a similar river.

A number of important Muslim dams were built in the Iberian peninsula. These included the dam at Cordoba with an overall length of 1,400 ft. Downstream from the dam were three millhouses that each contained 4 mills, as the geographer al-Idrīsī reported when he saw them in the twelfth century. Also below the dam is a large waterwheel. There are a series of eight dams on the river Turia in the province of Valencia. They are very securely built in order to withstand the sudden dangerous floods to which the river is subjected. They are also provided with desilting sluices, without which the canal intakes would soon become hopelessly choked.

These dams and their associated canals continue to provide for the needs of the province at the present time. It has been shown in modern measurements that the eight dams and their associated canals have a total capacity slightly less than that of the river. This, of course, raises the question whether or not the Muslims were able to gauge a river and then design their dams and canals to match. There seems no reason to doubt that they indeed had that capability.

Given that dam building had been an established practice since the times of the Sumerians and ancient Egyptians, it is not easy to isolate those elements that were Muslim innovations. On present evidence, it seems certain that the introduction of desilting sluices, the arch dam and hydropower were all Muslim inventions. The Muslims also probably perfected the technique of gauging rivers.

All the main water-raising machines were in existence in the Middle East before the advent of Islam. These included the Archimedean screw, the well windlass, the *shādūf*, the *sāqiya* and the *noria*. Because of their survival right up to the present day, and/or their importance in the development of machine technology, the last three of these are the most significant. The *shādūf* is illustrated as early as 2500 BCE in Akkadian reliefs, and it has remained in use throughout the world until now. Its success is due to its simplicity and its efficiency. It can be easily constructed by the village carpenter using local materials, and for low lifts it delivers substantial quantities of water. In consists of a long wooden pole suspended at a fulcrum to a wooden beam supported on columns. At the end of the short arm of the lever is a counterweight made of stone or clay. The bucket is suspended to the other end by a rope. The operator lowers the bucket and allows it to fill. It is then raised by the action of the counterweight and its contents are discharged into an irrigation ditch or a head tank.

The *sāqiya* was invented in Hellenistic Egypt, probably in the third century BCE. It is operated by an animal, usually a donkey, walking in a circle. On its shoulders and neck the animal wears a collar harness that transmits the power through two traces to a double-tree fastened to a drawbar. The drawbar passes through a hole in an upright shaft. This shaft carries the lantern-pinion, which is a type of gear-wheel consisting of two wooden discs separated by pins, the spaces between the pins being entered by the cogs of a vertical gear. This vertical gear has the cogs on one side of its disc and these protrude from the other side to form the wheel that carries the chain-of-pots, or potgarland. The component is therefore known as the potgarland wheel. It is erected on a horizontal axle over a well or other water source. The pots fill with water at the bottom of their travel and discharge at the top, like the shadoof, into a head tank or irrigation ditch. The saqiya was transited by the Muslims from the Middle East to Spain and eventually to the New World. In some areas it has retained its popularity to the present day.

The *noria* is perhaps the most significant, from a technical viewpoint, of the traditional water-raising machines. Being driven by water, it is self-acting and requires the presence of neither man nor animal for its operation. Essentially it is a large wheel constructed of timber. At intervals, paddles project outside the rim of the wheel, which is divided into compartments. The noria is provided with an iron axle and this is housed in bearings that are installed on columns over a running stream. As the wheel is rotated by the impact of the water on its paddles, the compartments fill with water at the bottom of their travel and discharge their contents at the top, usually into an aqueduct.

The point of origin of the noria is unknown, but it was certainly known in the Roman world and in China by the first century BCE. There is a possibility, therefore, that it was invented somewhere in the highlands of southwest Asia. The large noria at Murcia in Spain is still in operation, as are norias in various parts of the world, where they are often able to compete successfully with modern pumps.

Water wheels, as used in mills, were of three types: vertical undershot, vertical overshot, and horizontal. The first type was a paddle wheel mounted directly in a running stream. In the overshot wheel the rim was divided into compartments into which the water was directed from above, usually from an artificial channel or leat. Both vertical wheels required a pair of gears in order to transmit the motion of the water wheel to a vertical axle that led up to the millstones. In the horizontal type a jet of water from a reservoir was directed on to the vanes of the wheel, on the top of whose axle the millstones were installed. Various methods were used to increase the power and hence the output of mills. The wheel could be located in the piers of bridges or on boats moored on rivers, in both cases to take advantage of the increased rate of flow in midstream. In the Basra area in the tenth century there were mills that were operated by the ebb tide – about a century before the first mention of tidal mills in Europe. Apart from the production of flour from grains, water mills were also used for industrial purposes such as papermaking, the fulling of cloth and the crushing of metallic ores.

Bridges of all types were important in the Islamic world not only for communications but also for protecting the banks of canals from damage due to fording people and animals. In the mountains of Central Asia, such as the Tien Shan and Hindu Kush ranges, both cantilever and suspension bridges were used for crossing ravines. The great rivers of Egypt, Iraq, and Transoxiana were usually crossed by bridges of boats. In many cases, however, rivers and other obstacles were crossed by masonry arch bridges built of dressed stone or, sometimes, especially in Iran, of kiln-burnt bricks.

Two bridges in western Iran, built in the tenth century, are constructed with pointed arches. This type of arch, which was to be such an important element in European Gothic architecture from the twelfth century onward, had appeared in Syria and Egypt during the seventh and eighth centuries, but only as a decorative feature. These Iranian bridges are the earliest known occurrence of the pointed arch as a load-bearing component.

Chemical technology was a highly developed profession in medieval Islam. The most important writer on the subject was Muḥammad ibn Zakariyyāʾ al-Rāzī. Although he wrote a number of alchemical books, his major work, *Kitāb al-asrār* (The Book of Secrets), written early in the tenth century, leaves us with the impression of a powerful mind, much more interested in practical chemistry than in theoretical alchemy. *The Book of Secrets* contains a comprehensive list of pieces of equipment, many of which are still in use today. The chemical processes described or mentioned by al-Rāzī include distillation, calcination, solution, evaporation, crystallization, sublimation, filtration, and amalgamation. Arabic works were undoubtedly an important influence upon the development of European chemistry. Evidence for this influence is the abundance of Arabic words in the chemical vocabularies of European languages. Examples in English are alkali, alchemy, alcohol, elixir, naphtha, and many others.

Mining played an important part in the economic life of the Islamic world. Spread throughout this vast area were mines for all the important metals, precious stones and essential commodities such as salt, coal and petroleum. The oilfields at Baku were exploited by the Muslims on a commercial scale by the ninth century. In the thirteenth century Marco Polo reported that a 100 shiploads could be taken from Baku at one time.

Iron and steel were, of course, the most important metals for many industrial and military purposes. Cast iron was described about 1040 by the great scientist al-Bīrūnī – it was exported to many countries as a raw material. There was also an extensive steel industry which produced, among other grades, the famous Damascus steel. As far as we can ascertain at present, this came from a number of Islamic centers in the Middle East and Central Asia. But it was certainly produced in Damascus itself.

We have been able to mention only the more important areas in which Muslim engineers and technologists were pre-eminent for several centuries. In many cases Islamic ideas were transmitted to Europe, but it is important not to evaluate Islamic technologies only with regard to their contribution to their European counterparts. Technologists in the Islamic world were responding to the needs of society and were extremely successful in a number of fields.

See also: ►Qanat, ►Irrigation, ►al-Muqaddasī, ►al-Karajī, ►Surveying, ►Dams

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Technology in the New World

AARON SEGAL

The indigenous peoples of the New World were excellent builders. Although their construction tools were limited they managed to produce pyramids, temples, and other public buildings in the Andean Highlands, the lowland jungles of Central America and the Yucatan, and the central highlands of Mexico. There were ceremonial ballcourts built throughout the Caribbean as well as in what is now Mexico, Guatemala, and Belize. Construction in North America included the mound sites of the Midwest and the Southeast and the cliff dwellings of the Southwest. While estimated populations at these sites varied from the hundreds to the thousands these were all urban societies and civilizations.

These master builders relied on their own concepts, designs, craftsmen, and techniques. In spite of claims of trans-Pacific, trans-African and other exogenous contacts, the evidence is sparse and less than convincing. The civilizations of the New World evolved on their own with only limited contacts with one another over space and time. Their achievements as well as their failure are entirely their own, including matters of technology.

The New World societies concentrated on identifying, applying, and improving instrumental technologies, whether for agriculture, irrigation, construction, crafts, or other utilitarian uses. The legacy that has survived is one of warrior-kings, royal courts, artisans cum farmers, priests and scribes, builders and artists.

The peopling of the New World began approximately 15,000 years ago when climatic changes made migration from Siberia and East Asia possible across the Bering Straits. It took another 8,000 years for these small wandering human bands to reach Patagonia and spread throughout most of Middle and South America. Somehow they managed to keep fertility above infant mortality as they diffused on foot throughout the New World. Hunters and gatherers, they relied on stone age worked flint edges to kill, strip, and consume their prey. Their principal weapon, originating in Asia, was the *atlatl* or spear thrower improved with flexible sheets and stone weights. Bows and arrows were introduced later, also perhaps from Asia via the Arctic, and became a favorite weapon for hunting bison on the Great Plains. When the Tainos paddled island by island from Lake Maracaibo up the Caribbean Archipelago (AD 1000–1400) they were armed with an array of bows, arrows, stone, bone, and flint knives, *atlatls* and other weapons.

Those who undertook the Great Journey throughout the New World survived through environmental adaptation as they fanned out across two continents. Those who adapted to the Amazon Basin continued in a hunter–gatherer mode, learning the skills needed to survive in the tropical rain forest. The Arawaks, Tainos, and other voyagers to the Caribbean also relied primarily on hunting and gathering adapted to coastal fishing. Latecomers who remained in the Arctic or sub-Arctic turned to hunting, fishing, shelter, and other technologies to survive harsh winters.

Agriculture probably arose about 3000 BCE simultaneously in the Andean highlands and Central Mexico, first as a supplement to hunting and gathering and as a response to growing populations. Gatherers observed which seeds yielded what plants and began to cultivate on a trial and error basis. Teosinte, a high-protein precursor of corn, was first cultivated in Mexico, while potatoes were an early ecologically suitable cultigen in the colder Andes. The list of cultivated edible plants soon expanded to include manioc, squash, peppers, pineapples, and other New World originals, especially several varieties of beans. The Tainos learned to grow tobacco and to cure it as snuff in their Caribbean islands, which became valuable trade items.

Agricultural technologies evolved to include the use of digging sticks, irrigation canals, terracing and ridging, intercropping, and seed beds. Lacking draught animals fires were set to clear new land. The most sophisticated technique was that of the *milpas* practiced by the Aztecs who built silted mounds of fertile run-off materials.

Food processing and storage technologies were also innovated and widely diffused. The stone *metate*, or mortar and pestle, became the basic Mesoamerican tool for crushing corn. Ethnobotanical experience produced a variety of herbs, spices, and for the Mexicans chocolate to add to largely vegetable diets. As towns and cities grew, especially in the Andes and Mesoamerica, hunting declined in favor of limited domestication of chickens, turkey, pond fish, and small animals. However, animal protein was hard to come by in all the predominantly agricultural societies which relied on trade and food storage to supplement local corn, beans, manioc, and other staples.

Transport was a severe obstacle for all the New World peoples. Dogs were used to pull sleds and traverse with limited loads in the Arctic and on the Great Plains. Alpacas and llamas were semidomesticated and used for limited local transport in the Andes. However, everywhere terrain was rugged, surfaced roads were few and far between, and runners and headloads were the primary mode of transport. Sailing vessels were unknown and the canoes of the Tainos and others had to hug shorelines for safety. Although the concept of the wheel was known, and toy wheels were used in the Andes, the lack of roads and the natural obstacles impeded the development of wheeled vehicles. The Spanish introduction of the horse and the cow revolutionized transport in the New World. Trade previously was confined to what could be carried on men's backs. Thus the Aztec long-distance traders, *pochotes*, specialized in high-value items such as jewelry, ceremonial feathers, and weapons.

Confined to limited home markets, New World societies tended to invest their agricultural surpluses in exquisite crafts. As royal courts developed around ceremonial centers so did specialized artisans capable of meeting quality demands, as well as items for daily use. The oldest discovered textiles date back 3,600 years to the Peruvian coast and were made of cotton with intricate woven designs. Dyed cotton for personal clothing became widely diffused with pendants and ornaments often added. Excavation of Andean and other tombs has revealed the importance attached to clothing and jewelry and the high skills of the artisans. The Olmecs of the Mexican Southeast were the first to work in jade and turquoise as well as to create massive stone carvings. Metallurgy, especially in the form of masks, was highly accomplished in Mexico as well as among the peoples of what is now Costa Rica, Colombia, and Peru.

Ceramics and basket and gourd work were closely associated with the emergence of agriculture. Initial demands were for items used for carrying and storage. However, in the Andes and Mexico, as techniques improved, ceramics became an important ceremonial art form. Funerary jars, urns, water carriers, ceremonial masks, and other items are regularly depicted in sculptures and paintings and found in Aztec, Maya, and other tombs. Pre-Incan and Incan Andean societies also took pride in their varied and elaborate ceramics, baskets, and gourds.

Ceremonials were held largely outdoors, while palaces were for storage purposes. Most common people, including craftsmen, lived, ate, and slept in simple mud and brick dwellings. Their lords and masters lived in larger and more solid enclosures but with similar creature comforts. Building skills were directed at large-scale public constructions to honor the deities and/or fortresses for defense purposes. While kings lived in palaces with a few of their retainers many members of the court had to accept more humble accommodations. The benign tropical climate of the Caribbean contributed to nearly everyone's relying on hammocks and huts made of straw.

The Aztecs alone tackled the sewage and other waste disposal problems of man-made cities. They instituted barges along the canals of their capital at Mexico City, and also made an effort to keep water potable. At the Inca capital of Cuzco public hygiene was minimal as it had been in the Maya city-states. It may have been the scarcity of domesticated animals that reduced disease vectors in these highly crowded urban sites.

As builders the peoples of the New World concentrated their efforts on specific times and places. These included the Olmec (1000–600 BCE), Tectihuacan (AD 0–650), Toltec (1000–1300 BCE), and Aztec (AD 1400–1530) civilizations in Mexico, the Mayas (AD 0–900) in Guatemala and Mexico, and the Moche (AD 0–600), the Nazca (AD 0–600), the Chimu (AD 1300–1420) and the Inca (AD 1400–1530) in Peru. They were able to construct magnificent and lasting buildings in environments as different as lowland jungles and highland mountains. They moved massive amounts of stone and carved and fitted it exactly with simple tools, as well as working with wood. Their architects designed vast open spaces and compelling interiors. Their multistory edifices reached up to the heavens, and served sometimes as astronomical observation sites, while commanding the world below. Their equivalents are neither the medieval cathedrals of Europe nor the Acropolis of Greece. Instead they are the most significant continuing testimony to the uniqueness of the these New World civilizations and peoples.

While we can directly experience and marvel at these sites it is much more difficult to penetrate the intellectual worlds of their builders. The Mayas, prior to their collapse in AD 800–900, had a sophisticated writing system which was lost, as were many of their ideas about astronomy and mathematics. Similarly, the Nazcas of coastal Northern Peru who vanished around AD 600 may have had more advanced ideas about astronomy than their predecessors. The unevenness of historical experience and its inherently nonlinear nature is one of the sobering lessons of the history of science and technology in the New World. The Mayas alone invented a writing system which took nearly 450 years after the European Conquest to decipher. The Incas adapted a system of counting called the *quipu* for purposes of accounts and storage but never extended it into a mathematical base. The Aztecs excelled at urban planning, irrigation, and public health but showed little interest in writing.

The peoples of the New World were builders, agriculturalists, and craftsmen rather than scholars or theologians. The European conquerors came from an age of iron and steel with wooden ships, navigation, steel swords, guns, explosives, and literacy. They brought horses, cattle, and smallpox, measles, diphtheria, trachoma, whooping cough, chicken pox, bubonic plague, typhoid fever, scarlet fever, amoebic dysentery, and influenza.

See also: ►*Quipu*, ►Mathematics, ►Potatoes, ►Crops, ►Technology, ►Sugar, ►Animal Domestication, ►Metallurgy, ►Textiles, ►Nazca Lines, ►Stonemasonry, ►Swidden

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Telescope

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The telescope is an optical instrument used to make distant objects appear nearer and larger; it consists of one or more tubes with a series of lenses, mirrors, or both (refracting, reflecting and catadioptric models, respectively), through which light rays are collected, brought to a focus, and magnified. Despite their great variety, all telescopes have two basic parts: the objective, which intercepts and focuses the incoming light, and the mounting, which supports the objective. The telescope, which revolutionized astronomical research in the seventeenth century, is usually considered to be a European invention, though parallel discoveries occurred elsewhere, and some of its elements were developed earlier by other cultures.

The traditional Western account of the telescope's invention is quite complex. The use of hollow sighting tubes without lenses to observe stars had been known to the ancient Greeks, being recorded by Aristotle (384–322 BCE) and the geographer Strabo (ca. 63 BCE–ca. 19 AD). Lenses are mentioned by the playwright Aristophanes (ca. 450–388 BCE), and mirrors were investigated by Heron of Alexandria (ca. 60 AD). The geometer Euclid (ca. 300 BCE) and the engineer Archimedes (ca. 287–212 BCE) studied both. The investigation of lenses, mirrors, and sighting tubes continued throughout the Medieval period. The invention of spectacles, an important telescope precursor, occurred between 1285 and 1300 by an unknown Italian glassmaker, but Alexandro della Spina (d. 1313) and his friend Salvino d'Armati (d. 1317) are most often credited. Meanwhile, English Franciscan friar Roger Bacon (1211–1294) wrote extensively of spectacles and other optical devices, and influenced many later scientists with his research into the laws of reflection and refraction.

An enormous number of sixteenth century figures developed various combinations of perspective glasses and mirrors to enlarge distant objects, including the English father and son surveying team of Leonard (ca. 1520–ca. 1571) and Thomas Digges (1546–1595), mathematician William Bourne (d. 1583), Italian natural philosopher Giambattista della Porta (1534/5–1615), and Dutch mathematician Cornelius Drebbel (1572–1634). But the lack of documentary evidence has thus far left historians divided over whether these instruments were true telescopes or just magnifying glasses.

The first unambiguous accounts of the European telescope come from Holland around 1608. Most credit the Middleburg spectacle maker Hans Lippershey (ca. 1570–1619) with the first refracting telescope; but there are rival claims by Middleburg optician Zacharias Jansen (1580–ca. 1638), and Alkmaar inventor Jacob Metius/Adriaanzoon (1571–1635).

Early telescopes were first applied to military operations. But over the winter of 1609–1610, Italian physicist and astronomer Galileo Galilei (1564–1642) dramatically improved Lippershey's primitive device and turned it to the sky. His announcements of lunar valleys and mountains, sunspots, the phases of Venus, the moons of Jupiter, and much more (published in the March, 1610 *Sidereal Messenger*) thoroughly shook the ancient earth-centered cosmology of Alexandrian astronomer Claudius Ptolemy (ca. 150 AD). Similar observations were made between 1609 and 1612 by English polymath Thomas Harriot (1560–1621). The word "telescope," meanwhile, was coined in 1611, and was first printed in Julius Caesar Lagalla's (1576–1624) *Lunar Phenomena* of 1612.

Early Galilean telescopes, with one biconvex and one biconcave lens, suffered from both chromatic and spherical aberration, which left blurry images. The German astronomer Johannes Kepler (1571–1630) designed the improved Keplerian telescope of two biconvex lenses in 1611, but problems remained. It was not until 1636, when the Minorite friar Marin Mersenne (1588–1648) suggested replacing lenses with mirrors, that real progress could be made. Reflecting telescopes were designed by Scottish mathematician James Gregory (1638–1675) in 1663, and built a few years later by both Isaac Newton (1642–1727) and French physicist Guillame/Nicholas Cassegrain (fl. 1672); these models (Newtonian and Cassegrain) are still widely used today.

During the period 1610–1650, the telescope was carried by European explorers to all regions of the earth; frequently Jesuit missionaries exported it to non-Western cultures. However, there is evidence that other societies developed both the telescope and its various parts independently of Europe. Glass originated in Egypt about 3500 BCE and was first produced on a large scale by the Phoenicians, and lenses dating back to pre-Greek times (2000 BCE) have been discovered in Crete and Asia Minor/Mesopotamia.

Meanwhile, Arabic astronomers played a significant role in paving the way for the telescope. The mathematical laws of optical reflection and refraction in glass and other media were thoroughly investigated and extended by the physicist–astronomer Ibn al-Haytham (Alhazen, 965–ca. 1040). Ibn al-Haytham knew how to use spherical glass segments to magnify objects, and was familiar with spherical aberration and techniques to calculate the focal lengths of lenses and mirrors. Much of this knowledge was subsequently transmitted to Europe through Latin editions of his work, and especially through the texts of his Polish disciple, Witelo of Silesia (ca. 1230–ca. 1275). Bacon also learned much from Ibn al-Haytham.

Sighting tubes were also early employed by Arabic astronomers; al-Battāni (858–929) used them in his Raqqa observatory. Naṣīr al-Dīn al-Ṭusī attached one to a sextant at his Maragha observatory in 1259 to study the sun.

Meanwhile, Needham argues that Chinese opticians may have discovered the elements of the telescope either before, or parallel to, the Europeans. Though glass was developed fairly late (ca. 500 BCE), quartz rock-crystal had been in use since ancient times and lenses of both materials were employed to focus solar rays to start fires. Needham also claims the Chinese used smoky rock-crystal to observe sunspots and eclipses. An important text of Tan Qiao (the *Hua Shu* or Book of Transformations of about AD 940) records the use of planoconcave, planoconvex, biconcave, and biconvex lenses to make objects larger, smaller, upright, and inverted. Spectacles have often been considered a Chinese invention, but this is based on a garbled text; they were brought overland from Europe by 1300. As for catoptrics, Mohist opticians of the fourth century BCE studied both concave and convex mirrors, and were familiar with real and inverted images, focal points and refraction in different media. The use of concave mirrors to ignite tinder by focusing sunlight goes back to the Chinese Bronze Age; one of the earliest citations is dated 672 BCE.

Chinese sighting tubes made of bamboo are similarly old; the most important early reference is the (approximate) sixth century BCE *Shu Jing* (*Historical Classic*). By the *Huia Nan Zi* (*Book of Huai-Nan*) of 120 BCE, they were widely used in land surveying and triangulation; and by the twelfth century, they were standard navigational equipment for taking astronomical observations aboard ships.

Though many of these developments were contemporaneous with European discoveries, there are two parts of the telescope in which Chinese scientists can claim undisputed priority: the invention of equatorial mounting, and the development of clock drives, both of which are standard equipment on today's telescopes.

Astronomer Guo Shoujing (fl. 1270) developed the equatorial mounting now used on all modern telescopes for his "simplified instrument", which was basically a dissected armillary sphere related to the torquetum, an Arabic invention which had been recently imported (ca. 1267) to China from Persia. With an equatorial mounting, a rotation about only one axis (one parallel to the earth's polar axis) was needed to follow the curved paths of the stars.

Chinese physicists and engineers anticipated the fourteenth century mechanical clocks and clock-driven astronomical instruments of Europe by over a 1,000 years. Mathematician, geographer and astronomer Zheng Heng (ca. 78–ca. 142) constructed what Needham calls the "grand ancestor of all clock drives," a rotating bronze armillary sphere powered by a system of gears attached to a waterwheel. This device was used to predict the positions of various stars and planets. The later clock-driven armillary sphere of Su Sung (AD 1090) added a sighting tube to permit direct observation of a star as it moved over prolonged periods, resulting in a true "clock drive" for astronomy.

But despite Chinese priority in clockwork and mounting, just as in Europe, it was not until the seventeenth century that the disparate elements of the telescope were joined together. Though Chinese texts describe European telescopic discoveries from 1615 onwards, and Jesuit Father Terrentius/Johannes Schreck brought a telescope to China in 1618, Needham maintains that enough documentary evidence exists to assert a parallel, independent discovery by Suchow opticians Po You and Sun Yun Qiu. Between about 1620 and 1650, this pair constructed not only early telescopes, but also compound microscopes, magnifying glasses, searchlights, magic lanterns, and other instruments. Meanwhile, Sun Yun Qiu wrote a text on these and other optical devices, entitled *Jingshi* (*History of Optick Glasses*). But the first Chinese book on the telescope specifically was the *Yuan Jing Shuo* (*Far Seeing Optick Glass*) of Tang Ruo-Wang (Adam Schall von Bell) in 1626. *Yuanjing* became the standard term for the telescope, and by 1635 it was being widely used by Chinese artillery in battle.

Telescopes appear to have come to Indian astronomers fairly late. Indian craftsmen made glassware, lenses, and mirrors throughout the ancient and medieval periods. And *gola yantra* or armillary spheres, first mentioned in the *Āryabhaṭīya* of Āryabhaṭa I of Kusumpura (b. 476 AD), had clock-drives (powered by clepsydra) for stellar observation by the *Bhatadipika* of Parameśvara (ca. 1432).

But it was not until the seventeenth century that primitive telescopes were used in India. The celebrated astronomer and instrument-maker Sawai Jai Singh (1686/8–1743) employed telescopes to “show that Mercury and Venus get their light from the Sun as the Moon does” (*Zica-i Muhammad Shahi*); and though they revealed Saturn to be an irregularly shaped “oval,” these telescopes were apparently not good enough to resolve the rings, which had already been accomplished by Dutch physicist Christiaan Huygens (1629–1695) several decades previously, in 1659. Indian achievements in this area thus far appear to be rather derivative, but much research still needs to be done in this area.

See also: ►Jai Singh, ►Ibn al-Haytham, ►al-Battānī, ►Naṣīr al-Dīn al-Ṭūsī, ►Maragha, ►Guo Shujing, ►Zhang Heng, ►Clocks and Watches, ►Parameśvara, ►Āryabhaṭa

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Textiles in Africa

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Historians of African textiles now have at their disposal a wide range of oral and written documented sources. These describe significant centers of textile production over time, the raw materials, implements, and techniques used by the various cloth producers, varieties of fabric and techniques of dyeing and coloration, symbolic expression as reflected in the finished products, and the many functions for which the latter were used. The process of technological transfer within various parts of the continent and the elaborate structure of guilds and schools of apprenticeship are also better known to us as a result of the systematic collection of oral history in some areas.

From the Northeast African Nile region to West Africa and elsewhere, travel reports, missionary reports, and even autobiographies have provided details about aspects of the development of cloth making techniques. Herodotus in his travels in Egypt as far as the first cataract obtained specific knowledge about the implements used by the Egyptians and the existing division of labor. Such information has complemented the archaeological evidence brought forward by teams of Egyptologists as they continue to come in contact with numerous reams of cloth in the mummified corpses and burial goods which the Egyptian nobility, like some of their counterparts in West Africa, sent along with the dead to the afterlife.

In the case of Ethiopia, travel reports by missionaries, explorers, and travelers such as Francisco Alvarez, Jerome Lobo, Charles Poncet, James Bruce and Henry Salt, provide direct and indirect information on the variety of textiles in the Axumite and post Axumite realm. For West Africa in the eighteenth and nineteenth centuries, Mungo Park, Barth, and Baikie complement the perspectives diffused in the missionary reports of Trotter, Allen, and Crowther, who emphasized that the people of Onitsha, Eastern Nigeria, like their counterparts elsewhere, "manufacture their own clothes generally plain or fanciful with cotton grown in their farms" (Crowther 1968).

Archaeological reports have been no less useful than the eyewitness travel and missionary accounts cited. Reams of linen and cotton have been found in Egyptian tombs, and the Sudan, also one of the Nile Valley kingdoms, has yielded cloth and looms dating back to 500 BCE. The Igbo-Ukwu finds of Eastern Nigeria included thousands of artifacts, among which was cloth dated to the ninth century. The Bandiagara cliffs of Mali have yielded textile products dated to the eleventh century. The evidence from the excavated pits complements the various collective recollections reflected in poetry, song, and narrative accounts no less than the honorific codes and titles and range of linguistic terms accorded textile specialists and their products. Some city states and towns in the African continent gave their names to a product line, as was the case of Akwete and Okenne in Eastern and Central Nigeria, West Africa.

Whether in renowned Nigerian textile centers such as Kano, Iseyin, Bida or Akwete and Okenne, or in the Wolof empire of Senegal, the Bambara kingdoms of Mali, the Mossi Empire of Burkina Faso, or the Baule polities of the Ivory Coast, we can identify some basic raw materials, production instruments and techniques, as well as common tendencies relevant to textile not only in West Africa, where the latter regions were located, but also in Central, East, and Southern Africa. Raw materials were derived from vegetable or animal products and generally involved wool, camel hair, flax, cotton, the leaves of the raffia palm (*Raphia rufia* or *Raphia vinifera*), silk from cocoons, and bark from the baobab tree. In all the above cases, with the exception of bark, which was hammered into shape, there developed over time sophisticated spinning, weaving, and dyeing techniques which included the gradual invention and improvement over time of vertical and horizontal frames, lower and upper beams, beaters, shed sticks, hecklers, shuttles, and templars, all various components of the horizontal and vertical looms produced across the continent.

African textiles, by the nineteenth century, included a wide range of fabrics, each influenced by the base material from which the thread was made, the texture of the thread, the width of the strip woven cloth, the alignment of the thread, and the intensity of inlays and the dyeing procedure, whether starch resist or not. Indigo, guinea corn stalk, the bark of the locust tree, the leaves of the tombolo tree, combined with ash potash and any of a long list of colorants were used to produce blue, red, buff, rust, or brown and other colors. Dyes were derived from experimentation with vegetable and other products. The famous *Kente* cloth of strip woven silk (sometimes interlaced with threads of gold and very often confined to the Ashanti nobility), *Sanyan*, Western Nigeria's silk derived fabric, *Adrinkra*, the hand-printed cloth of the Ivory Coast, and *Sotiba* of Senegal, are some of the various types of textile products which have become household names in the continent.

A wide range of symbols was reflected in cloth through the representation of motifs of special shapes, figures, dimensions, and sizes. These were either impressionistically done by the use of geometrical shapes and symbols or were made to reflect naturalistic images derived from African cosmologies and indigenous belief systems. It was common for Dahomean quilts to portray images of the founding fathers of particular dynasties. A lion represented King Gelele and a buffalo King Gezo, whilst a representation of a ship was the symbol of King Agaza – all historic figures in the making of the Dahomean (Beninois) state. More recently, worldly events ranging from the American soap opera Dallas to statements about the prevailing economic reform programs have been coded into fabric. A study of African textile over the centuries yields information not only about changes in technical expertise and accretional gains made from the intraregional and interregional exchange of ideas, but also the prevailing lifestyles, philosophies, and world views of Africans in various parts of the continent. Textiles in themselves provide a rich source of historical information. They were associated with many activities and had many uses. They were a medium of exchange in barter, or units of currency in a wide range of commercial transactions. Tax payment was collected in the form of textiles and so too tribute. Since fabric differed in cost and the degree of technical expertise associated with various types, it was easy for it to become a symbol of wealth, extravagance, and conspicuous consumption. Cloth very often was a symbol of class affiliation. Saddle cloth and the overall accoutrements of the horse included specialized fabric, as did the panoply associated with Ashanti royalty. Cloth had special burial functions. Specialized fabric was associated with shrines of the dead. Marital gifts, whether prenuptial or not, tended to include cloth as part of the expected dowry. Decorative and symbolic objectives were matched by functional and practical ones. Cloth was used for protective purposes against the elements, as sheets and covers, and also to make rice bags, purses, or tents.

The reproduction of knowledge systems was done through institutionalized apprentice systems of guilds, each of which adhered to strict codes of conduct and behavior. Fees in cash or kind were paid by the apprentice who was expected to "gain freedom" after periods agreed to in the context of elaborate ceremonies. These guilds themselves had a hierarchy of officials who in many cases were of significant political clout. The teaching and training of spinners, weavers, and dyers was therefore organized in the context of established custom and practice, even though there was a general tendency for specialization to be restricted to specific lineages within various regions.

There is evidence that Africans imported cloth in the context of the trans-Saharan trade as well as the trans-Atlantic, but these importations were complementary to a wide range of indigenous textile products. It was not unusual for various political elites to flaunt some of the imported textiles along with indigenous products, or for textile specialists to unravel an epic of imported fabric with the objective of isolating particular reams of thread. The British industrial revolution had specific implications for African textiles, given the fact that factory produced cloth was cheaper with the mechanization of spinning and weaving. The successful transfer of textile technology from India to Britain by the nineteenth century meant that the British factory system was able to churn out some relatively attractive textile products for the African consumer. This, however, did not lead to the destruction of the indigenous textile sector which continued to be a dominant component of the informal sector well into the twentieth century, despite some ill-intentioned legislation and policies during the period of colonial rule.

Contemporary Africa is home to a wide variety of indigenous textiles. Local factory-produced cloth has had to compete with Taiwanese, Indonesian, and Dutch imports, most of which are imitations of indigenous African fabric. IMF and World Bank conditionalities tend to call for the removal of duties on imports and therefore undermine those local textile centers, some of which lack the productive capability to compete on the open market. In spite of these trends, however, there is every indication that African textile producers will continue to have a large share in the market and continue to experiment, innovate and produce the high quality textiles historically associated with the continent.

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Textiles in China

Dieter Kuhn

A textile is here understood as a woven fabric made from a wide range of raw materials. Some of these were silk, cotton, wool, and the bast fibers ramie (*Boehmeria nivea L.*), hemp (*Cannabis sativa L.*), and the bean- or vine-creeper (*Pueraria thunbergiana*), which possessed the greatest economic and cultural importance in pre-Mongol (prior to AD 1279) China. The development of textiles is described here on the basis of archaeological evidence and from the view of its cultural importance.

The origin of weaving can be traced back to basketry and matting techniques from the Neolithic. Impressions on ceramic sherds and fragments from the archaeological sites of Banpocun near Xi'an in Shaanxi and from Hemudu in Yuyao county in Zhejiang prove that they existed in China as early as the fifth millennium BCE. The earliest finds of textiles are from southeast China. There is a complicated fragment of fabric, made of *Pueraria thunbergiana*, found at Caoxieshan in Jiangsu province and dated to the fourth millennium BCE. Its structure features a combination of hand twining and loom weaving techniques. A number of silk belts, a piece of silk, and a scrap of ramie cloth were discovered in a bamboo box excavated from the site of Qianshanyang in Wuxing in northern Zhejiang, dated to ca. 2750 BCE.

Small stone-cut and jade figures were found in various Anyang sites from the the Shang period (sixteenth–eleventh centuries BCE). They clearly show "textile ornaments" which give an impression of Shang clothing and fashion. Apart from furs and leather, especially suitable as winter clothing and used for ceremonial occasions, hemp and silk were tailored. Tailoring does not mean cutting pieces of fabric so as to make them fit but simply sewing pieces of fabric together, only allowing a few corrections. It was probably the Shang people who introduced right side fastening and a hair-dressing style which could be distinguished from the barbarians. Most garments including lined garments were buttoned on the right side under the right arm. Very often the overlap of a robe was unbuttoned. *Obi*-like waist-belts kept the coat and the undergarments in position. Women's dress included a skirt. Women had their hair styled in a cylindrical shape, and flat rather high round caps were common. Upperclass people wore gaiters and shoes that curled upwards to the toe. Geometrically patterned fabrics (*T-, hui* and *lozenge*-patterns) were exclusively used as borders of garments, at the openings of the sleeves, at the collar, and along the overlap, for girdles and waist-belts, caps and hats. Colorful painted and embroidered silk was available to the higher echelons of Shang society. Certain important weaving techniques were applied to produce silk fabrics as early as Shang times:

1. Tabby weaves with threads of almost identical diameter and a thread-count of warp and weft between 8 : 7 and 75 : 50 cm^{-1};
2. Warp-faced tabby, also called rep or rib, where the number of warp-threads is roughly double the number of weft-threads per centimeter;
3. Monochrome tabby patterned with twill (3/1), very often named twill damask (*wenqi*). The ground weave is a tabby weave, and the pattern is woven in twill weave with the warp-threads forming the pattern;
4. Tabby crêpe (*zhou* or *hu*) with a thread-count of ca. 30 : 30 cm^{-1}. The warp-threads show a twist with 2,500–3,000 twists per meter. The weft-threads are twisted together from several threads in an *S*-twist showing 2,100–2,500 twists per meter. The strong twisting of the threads causes the crêpe effect;
5. crossed-warp weave technology was known and used.

The most important and spectacular textiles of the Zhou period (1045–221 BCE) discovered so far are from central and southern China, especially from Jingzhou in Hubei and from the region of Changsha in Hunan. In Western Zhou times (1045–771 BCE) the *jin* brocade appeared, an outstanding weave which on the one hand was produced on a rather complicated loom and on the other hand asked for expert craftsmanship. This so-called brocade was a new type of warp-faced compound weave with the warp divided into at least two series, normally of different colors. Even picks of weft interlace with the warp either in tabby or twill. Although this weaving method produced polychrome silk fabrics with a colorful shiny and mostly geometric pattern on the surface, its repertoire was still limited by the weaving technology at the time. Weavers exhausted the technical possibilities of their looms and composed scenes and figures which were evidently intended to be pictorial descriptions, but they are still symmetric with straight lines and cornered outlines. Embroidery helped to make the patterns of tigers, phoenix, dragons, birds, and blossoms appear more lively. The patterns were arranged in various ways adorning the silk robes of the fourth and third centuries BCE.

In 1972 outstanding textile fabrics and garments totalling more than 100 objects were unearthed at tomb no. 1 at Mawangdui in Changsha. The tomb belonged most probably to the Lady Dai (d. 168 BCE). Among the well preserved fabrics and garments there were more than a dozen robes of various make, such as 11 floss-wadded robes, one lined robe, three unlined robes, several blouses and skirts, two pairs of socks, four pairs of shoes, three pairs of gloves, pillow covers, 46 rolls of single-width silk fabrics, and many more items of daily life. The textiles exhibit an unrivaled excellence in weaving skills, the mastering of pattern design, and imagination in applying all sorts of patterning techniques. Favorite weaves were thin and loosely structered gauzes (*sha*) and lozenge-patterned leno (*luo*), a fabric of open structure which is made by crossing warp yarns.

The most sophisticated weaving techniques and looms were used to produce brocade with small geometric patterns. A new technical dimension of weaving becomes obvious with the pile-loop brocade, a velvet-like fabric with geometric patterns of different sizes. Forty silk garments are embroidered with the colorful and curvilinear designs of *xin qi* (abiding faith), *changshou* (longevity), *cheng yun* (riding on the clouds), and various plants and cloud patterns. Embroidery as a patterning technique lost some of its importance when by Eastern Han times (AD 25–220) the variety of weaving patterns was finally extended to include mythological beasts, birds, fishes, flowers, all sorts of four-legged creatures, and Chinese characters.

The brocade manufactured from Han to early Tang times (seventh century) was woven with warp-faced patterns. The colors of the previously dyed warp threads mounted on the looms dominated the patterns. The patterns could be as wide as the width of the fabric (ca. 50 cm) but their length was rather limited. Probably during the eighth century of the Tang dynasty a dramatic innovation took place. The weft-faced patterning method as it had already been practiced in a few woollen textiles from Han times was now widely applied to silk weaving. The advantage of weft-patterning was that the colors of the pattern produced by the weft could easily be changed, which resulted in larger and more vivid pattern units. Furthermore the dressing of the loom was facilitated. After the Tang dynasty, the weft-faced patterning method gained predominance in brocades and in other weaves. At the same time the cultural influence of Central Asia became evident in textile patterns. Apart from several hundred fragments of silks unearthed in 1987 from the underground palace of Famen Temple near Xi’an, most textile finds from the Tang period were discovered in the dry desert region of Turfan (Xinjiang province) and in the cave temples of Dunhuang.

If satin weave (*duanwen*) is classified as an irregular twill (*xiewen*), then satin could have been created as early as Tang times. Whereas the interlacing points of warp and weft in twill weaves are arranged in a continuous oblique line, those points in satin do not form a line but are evenly distributed, thus allowing long floats of the threads which give the fabric a glittering and at the same time smooth appearance. The French name *satin* was derived from the word *zaituni* which was used by Persian merchants to name the city of Citong at the coast of Fujian, another name for the famous commercial center of Quanzhou in the Song period (AD 960–1279). Several well preserved complete sets of official robes, garments of various types, underwear, and other textile items were found in three Song tombs. The tomb of Huang Sheng (1226–1243) in Fuzhou in Fujian province, who was the daughter of an official and married to an imperial clansman, contained 354 textile items, of which 201 were articles of clothing. The textiles are of top quality. The weavers and textile printers made use of the most advanced techniques of their time in producing figured leno (*hualuo*), gauze (*sha*), crêpe (*zhou*), and figured twill silks (*ling*). Even a few satin weaves (*duan*) are described. More than 30 textile items were discovered in the tomb of the student of the Imperial College Zhou Yu (1222–1261) in Jiangsu province, and the recently excavated tomb of Mme. Zhou (1240–1274) in Jiangxi province yielded 329 items of textiles. Among the many regional brocades produced, the pure red brocade from Sichuan (*Shu jin*), with a formidable array of realistically depicted designs, was most famous.

In northern China, where the Liao dynasty reigned from AD 916 until 1125, and in the Song empire, the use of various types of tapestry (*kesi*) became highly fashionable. Among the textiles recovered from the Liao tomb of Yemaotai, dated between 959 and 986, there was a shroud made of silk tapestry in gold threads with a powerful design of dragons. The forerunners of this *kesi* tapestry technique can be traced back to the *zhicheng* technique of Han times, an intricate inlaid pattern produced by the weft yarn employing the swivel weaving method. During the Yuan and the Ming dynasties the use of various types of weaves with gold threads (*jinjin*) increased. The weavers of Ming times, especially the craftsmen of the cloud pattern brocade (*yunjin*) from Nanjing mastered a swivel weaving method (*zhuanghua*) making use of colored wefts to form a pattern on a fabric of various weaves. In many cases a glossy satin served as ground for the colorful swivel weave.

Three types of pile fabrics were produced on a large scale in Ming and Qing dynasties. The *Zhang* satin, originally from Zhangzhou in Fujian, was a figured warp pile fabric. From early Qing times until the end of the eighteenth century its main centers of production were Nanjing and Suzhou. The *Zhang rong* was a velvet where in order to produce a pattern the loops in the pattern area were cut. Thus the velvet pattern stood out on a ground of loops. The *Jian rong* was a cut pile fabric made of black silk threads produced on looms in Nanjing.

For the dragon robes (*longpao*) of the imperial Ming and Qing courts, the formal Manchu court robes (*chaofu*), and the semiformal coats (*qifu*) all patterning techniques known at the time were employed. This applies especially to the robes manufactured during the reign of the Qianlong emperor after 1759. Many of the old weaving techniques were handed down from generation to generation and can still be found in China.

See also: ►Silk and the Loom

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Textiles in Egypt

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Egyptian textiles during the Dynastic Era (3100 BCE–300 BCE) were almost exclusively linen, although wool was not unknown. (Cotton and silk were introduced only later.) Linen was produced in three basic grades: royal linen, thin cloth, and smooth cloth. Production of royal linen, the highest grade, was a palace monopoly. Its manufacture took place both in the royal palace and in workshops associated with state temples. These workshops were supervised from the royal harem and were obligated to provide specific amounts of linen annually for use of the royal household and in temple rituals.

The Egyptians did not ordinarily color their linen because most of the dyes known to them were not colorfast. When one desired to dye either a piece of linen cloth or the thread used in embroidery, it was generally necessary to treat the fabric first with a mordant (one of several substances, such as alum, that would adhere to the fibers of the linen and allow the chemical bonding of the dyestuff) then with the dye itself. Thus, the typical color of Egyptian linen ranged from near white (from young, immature, flax plants) to golden brown (from fully mature flax).

Tomb paintings show that when Egyptians harvested flax, they pulled it up by the roots, rather than cut the stalks. Presumably this was to obtain the longest fibers possible. The stalks were first drawn through a comb-like devise to remove the seeds. The stalks were soaked, then beaten and sometimes scraped in order to separate the woody parts from the long, flexible fibers. A final combing prepared the fibers to be spun into thread.

Once dried, the flax fibers were rolled together, usually between the palm and the left thigh, forming a loosely twisted strand. These were wound into loose balls on a pottery reel, then stored in clay or basketry containers until ready for spinning. Based on artistic representations, the Egyptians used three different techniques to rotate the spindles while twisting the thread together. The supported spindle was rotated by being rolled between the palm and the thigh of the spinner. The grasped spindle was rotated between the palms. The suspended spindle was set spinning and allowed to drop and swing freely, its rotary motion being maintained by the weight of the whorl, the drum-shaped or dome-shaped stone or ceramic attachment near the top of the thin shaft of the spindle, which acted as a kind of miniature fly-wheel. The dropped spindle produced the most constant tension on the thread, permitting a finer and more homogeneous thread to be produced.

The earliest looms were simple ground looms in which the two beams supporting the warp threads were placed on the ground and held firmly in place with pegs. At about the beginning of the New Kingdom (ca. 1550–1085 BCE) we also begin to find examples of the vertical-framed loom in which the two beams were incorporated into a less portable rectangular wooden frame. Some have speculated that this innovation may have been introduced when Egypt was dominated by the “Sea People” or Hyksos (ca. 1700–1550 BCE).

When thread was ready for weaving, the warp threads were attached parallel to one another between the two main beams of the loom. In the simplest weaving, the weft thread was passed over and under alternate warp threads. On its return, the path of the weft thread was reversed, so that it passed on the opposite side of each warp thread. A stick or comb was often used to beat down and press the weft threads together. There are, of course, many variations on this basic tabby weave, some of them of considerable complexity. Various weaving patterns were used to provide some form of decoration in the fabric.

Based on artistic evidence, it appears that men were most frequently involved in the cultivation and harvesting of flax and in the preparation of the fibers for spinning. Both men and women (and even children) are shown involved in the spinning of the fibers into linen threads. Women, however, seem to be the ones who work at ground looms, while men more often are shown working at vertical looms. Whether this represents a true division of labor or only an artistic convention is unclear.

Woven cloth was cut either with a metal shears or a knife when the ancient Egyptian wished to fashion a piece of clothing. The pieces were sewn together using a fine linen thread and a needle of polished wood, bone, or metal (usually copper or bronze, but occasionally gold or silver). The pieces were held together during sewing with pins of the same composition. Both needles and pins tended to have larger dimensions than modern examples. Pins were frequently capped with a looped head, which may have served a decorative purpose. Seams and hems were frequently rolled and secured by a rather crude whipping stitch. Garments that might experience greater stress or wear might be joined instead with flat seams. There were, as today, many experiments with decorative sewing in order to produce an aesthetic effect.

Fine linen was apparently quite valuable. Considerable effort was often expended to repair damaged garments. Usually repairs were in the form of darning (reweaving), rather than patching. The more ordinary grades of linen, however, were repaired with considerably less effort. A frayed edge might be bound carefully with a whipping stitch, but more serious damage often led to the object being discarded and replaced. Sometimes outworn garments were torn into strips to use in wrapping mummies.

From as early as the Old Kingdom (ca. 3000–2700 BCE), there are indications that laundering was done for wealthy households and temples. Washermen often formed a kind of guild. In the New Kingdom, the Superintendent of the Washermen seems to have enjoyed nearly as much prestige as the Sandal Bearer within the royal household. (Of course, in most households, the task would have fallen to the women or slaves.) Clothing was picked up regularly from subscribing households, identified with specific markings and listed on *ostraca* (pottery shards or flakes of limestone), and taken to the riverside laundry. There it would be treated with natron or other types of surfactants, beaten with sticks or stones, rinsed, wrung out, and spread to dry and bleach in the hot Egyptian sun. When fully dry, it would be folded, bundled, and returned to its owners.

As is often the case, much of our knowledge of the processes for textile production, use, and care is derived from scenes portrayed in the funerary art of the social elite, coupled with study of surviving examples (and Egypt's dry climate has helped to preserve many pieces of textile). These reveal a remarkably sophisticated industry for production of cloth and clothing. Modern archaeology increasingly realizes the importance of textile evidence in dating artifacts, as well as in offering invaluable evidence of the daily life of all classes of ancient Egypt society.

See also: ►Dyes

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Textiles in India

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India may be described as one of the ancient centers of the cotton textile industry, since early evidence of cloth has been found in prehistoric archaeological sites. The spinning and weaving of cloth was very much a part of everyday life in ancient India. The loom is used as poetic imagery in several ancient texts. The *Atharvaveda* says that day and night spread light and darkness over the earth as the weavers throw a shuttle over the loom. The Hindu God Vishnu is called *tantuvardhan* or "weaver" because he is said to have woven the rays of the sun into a garment for himself.

It is interesting to note that in the third or second century BCE, when the cotton industry in India was in a flourishing state, in Europe cotton was still virtually unknown. The Greek scholar Herodotus thought that cotton was a kind of animal hair like sheep's hair. At the beginning of the Christian era, Indian textiles figure prominently in the trade with Rome. Arrian, the Roman historian, testifies to the export of dyed cloth from Masulia (Masulipatnam on the Coromandel coast), Poduca (Pondicherry), Argaru (Uraiyūr in Tanjavūr district, Tamil Nāḍu) and other places in south India. Legend has it that Indian cloth was purchased in Rome for its weight in gold. The quality of Indian dyeing too was proverbial in the ancient world, and in St Jerome's bible, Job says that wisdom is more enduring than the dyed colors of India. Indian textiles even passed into Roman vocabulary as is seen by the use as early as 200 BCE of a Latin word for cotton, Carbasina, derived from the Sanskrit *kārpasa*.

The history of Indian textiles constitutes one of the most fascinating and at the same time tragic chapters in Indian history. In the sixteenth century the Portuguese first set foot on Indian shores and were followed in quick succession by the Dutch, English, and French. For the next hundred years "Indian cotton was king" and Europe was in the grip of what economic historians describe as "the calico craze." Indian textiles were used in the Middle East, Africa, and Europe not merely as dress material but also as coverlets, bed spreads, and wall hangings. The joint English sovereigns William and Mary are described as having landed in England in 1689, resplendent in Indian calico. Daniel Defoe, the author of *Robinson Crusoe*, commented that Indian calico, which at one time was thought fit to be used only as doormats, was now being used to adorn royalty.

However, there was a dramatic reversal of fortune in the eighteenth century. The cotton revolution in England rendered redundant the products of Indian handlooms. The first ban on Indian textiles was imposed by the British crown in 1700 and repeatedly after that. By the end of the century, instead of Indian cloth being exported abroad, the Indian market was flooded by the machine-made cloth of Manchester and Lancashire. Around the same period, India was hit by one of the worst famines beginning in the late seventeenth century and continuing through the eighteenth century. The words attributed to Lord Bentinck, the Governor of India in the 1830s, that "the bones of the weavers are bleaching the plains of India" are a dramatic but apt description of the fate of the Indian weavers.

The eclipse suffered by the Indian textile industry lasted until the early twentieth century until its grand revival under Gandhi, who initiated the *khādi* movement. The *charkhā*, or Indian spinning wheel, and *khādi*, or homespun cloth, became symbolic of the Indian struggle for independence. Foreign cloth was burnt in the public squares and the Indian spinning wheel became a part of the home of every Indian patriot.

Since Independence, a sea change has occurred in the traditional Indian textile industry. The changeover to power looms and jet looms and the introduction of computer designs is setting new traditions in Indian textiles. In the course of its historical vicissitudes, the Indian textile industry has gone through a process of change as well as cultural assimilation.

Indian Textile Technology

The first process in the weaving of a cloth is warping and sizing, and in India this is done in the open. Bamboo sticks, about one hundred and twenty in number, are fixed upright in the street or what is called the warping grove, at a distance of a cubit from one another. Rows of women walk up and down the line, each carrying a wooden spindle in the left hand and a bamboo wand in the right. As they walk, they intertwine the threads between the split bamboos. These threads are then stretched horizontally from tree to tree, evenly washed with rice starch and carefully brushed. The right amount of tension in the warp in required to prevent the yarn from breaking while on the loom.

In India spinning was and still is almost exclusively the occupation of women. More specifically, this was the sole occupation of destitute women and widows. It is interesting that this corresponds to the English notion of the 'spinster' as one who has to spin for her livelihood since she has no one to support her.

The earliest looms in use in India were either the pit loom or the vertical loom. The *Atharvaveda*, probably compiled in the early pre-Christian era, says, "A man weaves it, ties it up; a man hath borne it upon the firmament. These pegs propped up the sky; the chants, they made shuttles for weaving... (sic)." However, the most common type of loom in use was the horizontal pit loom in which the loom is placed inside an earthen pit and is operated with foot treadles. By depressing the pedal with one foot and raising the other, one set of threads get depressed and the weaving shed is formed through which the throw shuttle is shot across by hand. References to such looms are scattered throughout ancient and medieval inscriptions. Around the fifteenth century one begins to get reference to the draw loom. This would consist of several levers and so enable the weaving of complex patterns. The introduction of the fly shuttle in the 1930s toward the end of British rule in India resulted in the partial mechanization of loom technology and in another three decades this was followed by the introduction of the jacquard. Nowadays, partially mechanized looms, power looms, and jet looms are displacing the traditional Indian handloom.

Traditional Indian Costumes

Different types of cloth are worn and woven in the different parts of India, since this is a vast land with varying climates. Generally, men tend to wear a longish lower cloth of about one and a half yards in length, called *dhōti* or *lungi* in the north and *veshti* in south India, while the traditional upper cloth consists of a single piece of cloth called *aṅgavastra*. However, in hot weather, men generally go without the upper cloth. In many parts of northern India, men also wear a head gear against the dust and heat. This is especially true of desert regions like Rajasthān. The Indian women wear large skirts or loose trousers called *salwār* and longish or short jackets. Alternately, they wear a six-yard piece called a *sāri* and a blouse for the upper part. In the colder parts of India, such as the Himalayan mountain ranges and Kushmir, the garments are thicker and more elaborate, including warm woolen shawls and heavy jackets. It is noteworthy that in antiquity, stitched garments such as shirts, trousers, and blouses were hardly ever worn in India. In the ancient sculptures and paintings such as the ones at Amarāvati or Brahadīśvaram, it is only the menials, palace attendants, common soldiers, and dancing girls, all of them belonging to the lower echelons of society, who are depicted wearing stitched garments. Such garments are never depicted on the upper classes or royalty nor on the images of gods and goddesses. A plausible reason may be the association of impurity and pollution with stitched cloth.

Colors and Designs in Textiles

Traditional Indian textiles reflect the Indian ethos. There is an aura of religion and romance around Indian weaving. Everything is significant – the colors chosen, the motifs, and the wearing occasion. Crimson or shades of red are very auspicious and worn by women on the occasion of their marriage as well as by ceremonial priests in certain parts of India, such as the Madhvā Brāhmins of Karnātaka. White represents purity and ochre, renunciation, and these are the colors worn by Hindu widows as well as ascetics. Yellow and green denote fertility and prosperity and are worn in the spring. Black is considered inauspicious, although pregnant women in south India wear black, perhaps to ward off the evil eye. As late as the eighteenth century, coloring was done entirely through vegetable dyes such as madder and indigo, although now dyers have almost entirely switched over to chemical dyes except in the case of highly specialized textiles like the *kalamkāris*.

The earliest designs on Indian textiles seem to have been geometrical. A twelfth century Sanskrit text called the *Mānasōllāsa* described textiles designed with dots, circles, squares, and triangles. The depiction of flora and fauna was related to religion and popular beliefs. The lotus, which has great spiritual significance in Hinduism, and the mango design are among the most popular Indian motifs. Swan, peacock, parrot, and elephant are also commonly depicted. The tree of life, which symbolizes fertility and prosperity, is another auspicious motif. All these designs are patterned on the loom itself and it may take a handloom weaver working on an ordinary frame loom as long as 30 days to weave an elaborate six-yard *sāri* with designs and gold lace. As the weaver weaves, he also sings the special loom songs, a tradition which has now almost entirely died out except perhaps in some interior weaving villages in Uttar Pradesh or the remote south. These loom songs tell of the glory of particular weaving castes or they are full of esoteric religious metaphors describing god as the eternal weaver, weaving the web of life, and the human body as the cloth he has woven.

Textile Varieties

Traditional Indian textiles are unique and unparalleled for their beauty. The *jāmdāni* is an elaborate textile which is woven with multiple shuttles and resembles tapestry work. Floral motifs called *bootis* in gold or silver lace are scattered over the body with heavy gold lace on the borders. The most striking of these designs is the *pannā hazāra*, literally a thousand emeralds, in which the flowers shimmer and gleam all over the sari. The Benarsi sāris called *Kiṁkhābs* woven in Uttar Pradesh are legendary for their loveliness, although Benaras in the north and Kāṅchipuram in the south were traditionally associated with pure cotton rather than silk. It was the British who introduced sericulture in Kanchipuram in the nineteenth century. Gadhwāl and Venkaṭagiri saris of Andhra and the Īrkal saris of Karnataka specialize in rich gold borders and heavy panel-like *pallūs* (that portion of the sāri which is draped over the shoulder). Another variety is the tie and dye (called variously *bandini, ikāt,* or *chungdi*) produced in Rajasthān, Orissa, Andhra Pradesh, and Madurai where the fiber is tie-dyed before weaving. A unique Andhra textile is the *telia*, which was soaked in oil before weaving and catered exclusively to the West Asian market because it was woven to suit desert conditions. This textile appeared in the sixteenth century with Muslim rule and died out with the collapse of the Islamic empires. Another textile which became popular in the mughal period was the *mashroo* (also the *himroo*) in which cotton was used in the warp and silk in the weft. Initially these were used as Islamic prayer mats by the Mughal nobility who were forbidden by Islamic tenets to use any animal product. They therefore contrived the mashroo which enabled them to have their comfort without violating the religious tenet against the use of pure silk.

Textiles also form an important part of temple ceremonials such as the flag cloth hoisted in temples, the garments put on the deity, the cloth covering the chariots in which the deities are taken out on a procession and the ritual dance costumes. The *kalamkāri* cloth of Andhra, in which mythological stories are sketched minutely on cloth with a fine pen as well as the *Nādhadwāra pichwāis* of Rajasthan, are of this genre. In India it is also the practice among wandering groups of minstrels to render dramatic narrations of mythological stories, and the elaborately painted screens used on these occasions form an important aspect of traditional Indian textiles.

See also: ►Colonialism and Science

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Textiles in Mesoamerica

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Because textiles are rare among the artifacts of cultures known to us only archaeologically, any analysis of them, or of the technology of their production, must be pieced together from indirect sources. In Mesoamerica, while archeological finds attest to the existence of various textile technologies at specific dates, much of our understanding of the subject comes from ancient Maya, Mixtec, and Aztec books, stone sculpture, painted pottery, murals, clay figurines, European documents from the time of the Conquest, and modern textile traditions.

Though the physical environment of Mesoamerica generally precludes the survival of perishable artifacts, textiles have none the less survived from certain areas. The majority, mostly small fragments, have been found in dry caves in the arid regions of Mexico. In the humid southern lowlands very little has survived, some 2,500 carbonized fragments dredged from protecting mud at the bottom of the Sacred Well at Chichen Itza are the most important single find.

The oldest textiles to survive in Mesoamerica are cordage, netting, and basketry, worked in vegetal fibers other than cotton, with early examples dating to at least 7000 BCE in Oaxaca and to 5000 BCE in central and northern Mexico. Such textiles are fashioned from the leaves and stems of various plants worked without the benefit of a loom. In instances where fibers were extracted from their plant sources, they were probably spun by rolling them together between the hand and thigh, as no tools for spinning have been found. Spindle whorls and evidence of loom woven textiles appear much later.

The earliest evidence for loom weaving in Mesoamerica consists of fabric-impressed ceramics datable to 1500 BCE, at which time spindle whorls also begin to appear. Woven cotton fragments follow soon after. These early woven textiles are worked in plain weave and almost certainly were created on a backstrap loom. From these simple beginnings, a sophisticated textile industry developed.

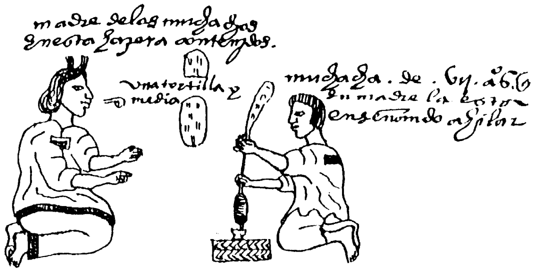
The weaving process begins with the selection and preparation of suitable materials. The predominant fiber of woven Mesoamerican textiles was cotton, *Gossypium* spp., with both annual and perennial varieties reported at the time of the Conquest. Cotton was cultivated in at least two colors, white and brown, and traded throughout ancient Mesoamerica. Other fibers, generically termed istle (from the Nahuatl *ixtli*), were drawn from the leaves and stems of many plants of more local distribution, including *Agave* spp. and *Apocynum* spp. Both cotton and istle required much preparation prior to spinning and weaving. Cotton was carefully picked over, its numerous small seeds and other vegetal debris removed by hand and the mass of fiber then fluffed or beaten to produce a uniform, smooth mass. Istle, on the other hand, was toasted, split, and scraped to remove the plant flesh from fibers which were then washed, dried, and combed. No animal fibers are known to have been used in ancient Mesoamerica. Textile headdresses incorporating human hair, however, have been found.

Both cotton and istle were spun on the spindle, a simple device consisting of a "whorl" wedged onto the end of a straight-tapered shaft. A mass of fiber was attached to the shaft, which was then twirled, imparting twist. The whorl helped the device to spin easily and for an extended time, and provided weight against which the fiber could be drawn out and twisted into thread. Different fibers required different types of spindles and sizes of whorls. Cotton, because of its very short fibers, was spun on a small spindle, the lower end of which was supported in a bowl or on the ground. The longer istle fibers required a larger, heavier spindle. Yarns of any size could be created and some as fine as 0.005 mm in diameter have been recovered. Yarns could be used singly, or two or more individually spun strands could be retwisted ("plied") together. A mixture of cornmeal and water was likely applied to some yarn to smooth and strengthen it for weaving.

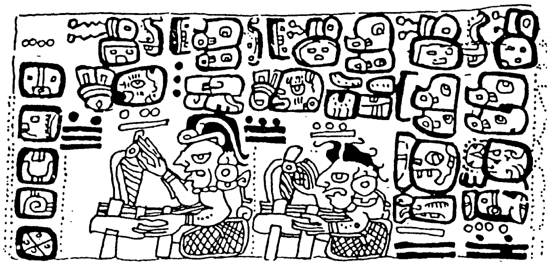
While there is little archeological evidence for the use of dyes, Post-Classic pictorial codices and reports of the *conquistadores* both attest to the vivid colors of Mesoamerican textiles. Plant dyes probably included indigo (*Indigofera anil*) for blue, brazilwood (*Caesalpinia* spp.) for red, logwood (*Haematoxylon campechianum*) for black or blue, annatto (*Bixa orellana*) for orange, and many other leaves, seeds, roots, barks, and fruits. Two animal dyes were important: on the Pacific coast, purple was extracted from small mollusks of the genera *Thais*, *Murex*, and especially *Purpura*, while in arid regions, cochineal (*Coccus cacti*, a scale insect of the order Hemiptera) was cultivated on the prickly pear cacti (*Opuntia* spp.). The beautiful red produced by cochineal was much admired by the Spanish, and the dyestuff became a major export to Europe following the Conquest. Mineral pigments, such as ochre, iron pyrite, cinnabar, carbon, copper sulfate, and "Maya blue" clay were known, and there is some evidence for the use of mordants which make dyes more permanent. Dyes and pigments were applied by painting, by stamping or rolling with figured clay implements, and by immersion dyeing. Patterns were produced during dyeing through the application of resists and through tying-off of sections to create undyed areas of yarn or fabric. Fabric incorporating tie-dyed warp, called *jaspe*, is still produced in Guatemala today.

Once suitable yarns were spun and dyed, the process of setting up the loom began. The *Florentine Codex*, a documentary of Aztec life and custom written by the Spanish friar Sahagún just after the Conquest, illustrates the weaver's equipment, including spindle, warpboard, loom sticks, backstrap, and batten. It also describes the training of weavers, from the presentation of the newborn girl with miniature weaving equipment, to the day of a woman's death when her loom and spindle were burned in the funeral pyre awaiting her in the afterworld. In the *Mendoza Codex*, created by Aztec scribes at the order of the first Viceroy of New Spain, there is a section devoted to a mother's training of her daughter in domestic chores. It portrays the child's instruction in spinning (Fig. 1) and weaving, from ages 3 to 14, her food rations, and punishments for unacceptable work.

Information about weaving is also contained in Maya books, whose almanacs provide endlessly repeating prognostications for the timing of certain quotidian activities. One almanac in the *Madrid Codex* depicts the process of preparing the warp for the loom (Fig. 2). The weaving goddess, named *Sak Na* in the accompanying hieroglyphic text, is shown seated cross-legged with her left hand against a horizontal frame supported by at least two vertical posts and with lines stretched between their projecting upper parts. Her raised right hand holds an inverted spindle from which thread reaches to the frame before her. While there have been varying interpretations of the activity portrayed in this illustration, the overhead texts clearly read: *Sinah u chuch Sak Na*, or "She strings her warpboard, *Sak Na*," describing in ancient Mayan the process depicted. This manner of preparing the warp yarn, by measuring and stretching it



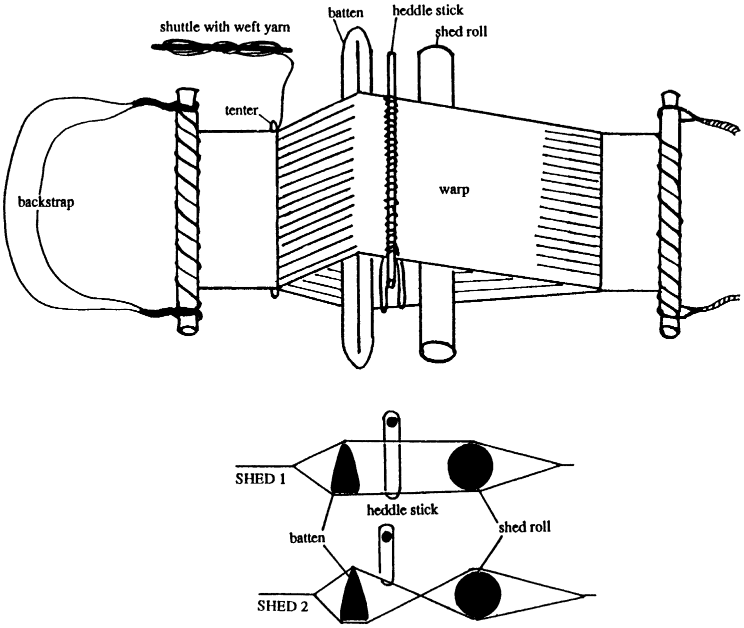
Textiles in Mesoamerica. Fig. 1 An Aztec woman instructs her 7-year-old daughter in the art of spinning cotton on a supported spindle. The child's ration of one-and-a-half tortillas is shown between them (from *Mendoza Codex*, page 59; from a photo of the codex).



Textiles in Mesoamerica. Fig. 2 A Maya almanac illustrating the goddess *Sak Na* preparing her warp (from *Madrid Codex*, page 102; drawing after Villacorta).

between vertical posts on a warping frame, was in use at the time of the Conquest and survives to this day. It is the initial phase of preparing a backstrap loom (Fig. 3) for weaving.

As the warp yarns are measured, they are wound alternately to one side and the other of a pair of vertical posts, thus creating a lease which maintains their order and allows the easy selection of alternate threads. Once wound, the opposite ends of the warp are secured to bars which form the ends of the loom, and a large, smooth, rounded stick (the shed roll) is placed through one side of the lease. The shed roll allows for the lifting of those threads which travel over it, one half of the



Textiles in Mesoamerica. Fig. 3 The structure of a backstrap loom, showing component parts and how they are used to create two sheds for weaving (drawing by Carolyn Jones).

total warp threads in alternating order, creating the first opening or shed. The remaining threads, which travel under the shed roll, are individually secured to a second stick (the heddle). By pushing the shed roll back and lifting the heddle, the other half of the warp threads are raised, creating the second shed. This is the mechanism by which Mesoamerican weavers created plain woven fabric.

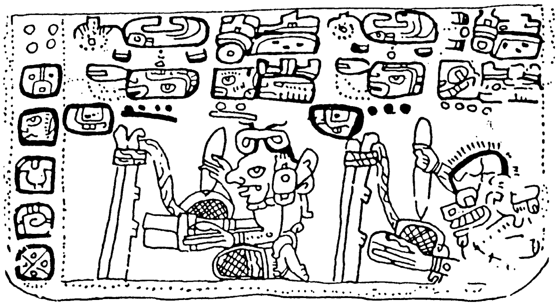
Before the loom is ready for weaving, additional implements are required. A long, heavy, straight-sided wooden stick (the batten) which can be turned on its side to enlarge the shed through which yarn (the weft, carried on a shuttle) will pass, and which is used to beat that weft into place, is employed continuously during weaving. A thin stick (the tenter) is usually attached to the fore-edge of the weaving to regulate the fabric width. Finally, the far end of the loom is tied to a tree or post, while the close end is attached to a strap which travels around the weaver's hips as she sits on the ground. By adjusting the position of her body, the weaver controls the tension of the warp of her loom.

This action is illustrated in the *Florentine*, *Mendoza*, *Matritense*, *Dresden*, and *Madrid Codices*, and in clay figurines from Maya burials on the island of Jaina. The *Madrid Codex* contains an almanac comprised of two episodes (Fig. 4). The first is illustrated with a crude drawing of a skirted female on her knees, her left hand supporting a backstrap loom, her raised right hand inserting the batten. Over the scene is an explanatory text that reads: *Och-i ti te' Ch'ul Na Che'el*, or "Divine *Na Che'el* (another name for the Maya weaving goddess) weaves at the post."

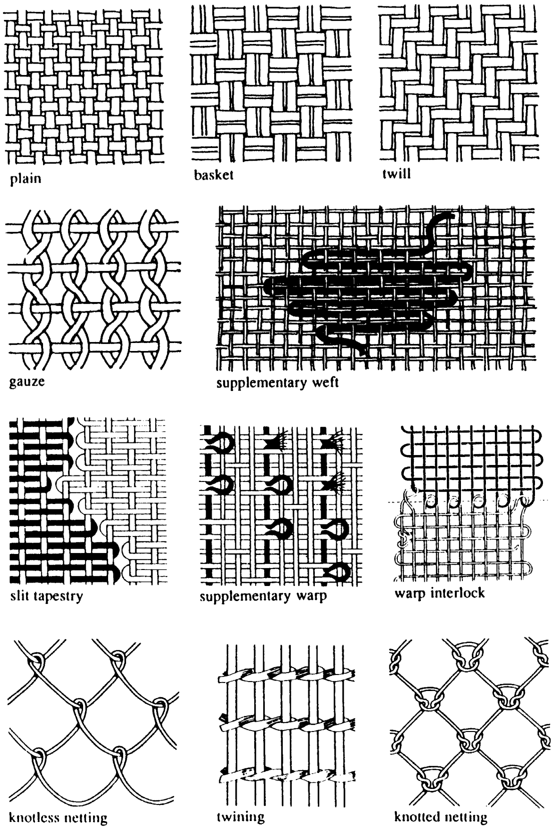
Simple in construction, the backstrap loom was well suited to the Mesoamerican woman's environment. Spinning and weaving were but two of her many daily chores, and the easy portability of the backstrap loom allowed its being rolled up for safekeeping when not in use, or set up when and where convenient. The simplicity of the equipment, however, did not preclude complex weaving. Extant fabric fragments display a wide variety of techniques. Among the simple weaves are plain, semibasket, basket, twill, and gauze. More complex weaves include supplementary weft brocade, tapestry, inlay, supplementary warp patterning and pile, warp interlock, and layer exchange double cloth (Fig. 5).

The structure of the backstrap loom determined several qualities of the fabric to be woven. The size of the finished cloth was determined when the loom was set up, and was limited in both width (by the weaver's armspan and her need to position herself at the center of the loom for proper tensioning), and length (the longer the warp, the more cumbersome and difficult it was to weave). When a large fabric was required, it was woven in small rectangles and pieced together, usually without cutting. Mesoamerican fabrics could include four finished edges and tended to show more warp than weft, with warp counts as high as 78 threads to the inch recorded.

In addition to weaving, ancient Mesoamericans were familiar with twining, braiding, plaiting, knotted and knotless netting, sewing, and embroidery. Methods for making leather, felt, bark cloth, and paper were known.



Textiles in Mesoamerica. Fig. 4 A Maya almanac illustrating the goddess *Na Che'el* weaving at her backstrap loom (from *Madrid Codex*, page 102; drawing after Villacorta).



Textiles in Mesoamerica. Fig. 5 Some structures known from ancient Mesoamerican textiles. The bottom row provides nonwoven techniques for comparison with the loom-woven structures shown above (drawing by Carolyn Jones).

At the time of the Conquest, new materials and techniques were introduced, including needle knitting and the use of sheep wool and silk. In some areas, the treadle loom came into use, and men entered the field of textile production. These different technologies survive side-by-side with backstrap weaving today.

The importance of textiles, and particularly of weaving, to the ancient cultures of Mesoamerica must not be underestimated. Weaving was not simply a means of producing necessities of daily life, but was an expression of the Mesoamerican world view. The act of weaving was seen as a basic creative force, analogous to the original creation of the world in Mesoamerican myth. The symbolic significance of the act of weaving lives on in the complex patterns of the modern Maya woman's *huipil* (or traditional poncho-like garment), each of which is a cosmogram that places the weaver at the center of the universe. Many designs used today are notably similar to symbols depicted in carved stone representations of textiles from the ninth century, thus displaying remarkable continuity with a lengthy and rich Mesoamerican textile tradition.

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Textiles in South America

AMY OAKLAND RODMAN

Unlike most parts of the world where discoveries of ancient textiles are unusual, the Pacific desert coast and dry western Andean slopes have preserved enormous quantities of textiles, wood, feathers, plant material, and other usually perishable artifacts. Most of the best preserved textiles were originally part of burial furnishings left in ancient cemeteries stretching from central Peru to northern Chile. The far north Andean coast (modern Colombia, Ecuador, and northern Peru) encounters periodic torrential showers which have destroyed most ancient remains. Few textiles have survived from the highland wet and dry climate or the rainforest regions of the eastern Andean slopes stretching to the Atlantic ocean.

It is apparent that desert conditions and the careful preparation of tombs are the two elements most responsible for the preservation of ancient Andean textiles. Beginning around 3200 BCE and continuing until the conquest of the Andes in AD 1532, it is possible to reconstruct textile technology in coastal regions and occasionally to witness highland development through textiles preserved in coastal sites.

Archaeologists have designated the Cotton Preceramic (3200–1800 BCE) as a period when a variety of coastal cultures developed cotton twining, looping, and other nonloomed textiles before the use of the heddle loom or ceramics. Major discoveries at Huaca Prieta, La Galgada (a highland site with remarkable preservation), and in Asia have determined that not only were large quantities of cotton textiles used, but that some were elaborately patterned. Images on Preceramic cotton textiles include condors with outstretched wings, two-headed snakes, and humans or deities with splayed feet, all subjects with similar presentation to images which continue in the art of many subsequent Andean cultures. Designs are created through transposing twined elements, often combining a change in regular yarn movement with alternating colored yarns. Cotton dyes include indigo for blue and unidentified, red, yellow, and brown colors. Thicker plant fibers were twisted into sturdy twined mats, while cotton was used for looped caps and twined mantles.

Beginning in the Initial Period (1800–800 BCE) and the following Early Horizon (800–0 BCE), Peruvian textiles developed through the use of the heddle loom. Hundreds of painted Early Horizon cotton plain-weave textiles discovered near Karwa on the Peruvian south coast identified fabrics with designs very similar to stone carvings from the north highland pilgrimage site of Chavin de Huantar. This important and well-preserved painted ritual cloth provided evidence of the ways in which textiles were used to transport religious imagery throughout the Andes beginning in very early periods.

Camelid fibers, sometimes termed "wool" yarn, from the hair of the nondomesticated guanaco and vicuna or the domesticated llama and alpaca, were introduced into coastal weaving during the Early Horizon. Camelid hair is more easily dyed than cotton and its introduction into coastal technology is usually based in its application in brilliant colors for weft-patterned structures. The first all-wool tapestry textiles appear in coastal cemeteries during this period and it is likely that these identify an ancient highland wool technology rarely preserved in the highland regions of natural camelid habitat.

The famous Paracas textiles were woven and embroidered on the southern Peruvian coast during the Early Horizon. On the Paracas Peninsula, elite individuals were buried with hundreds of embroidered shirts, skirts, mantles, feather fans, and golden objects all wrapped inside enormous plain woven cotton winding cloth. The multicolored wool embroideries depicted repeating human, deity, and animal images and were executed in stem stitch on plain-woven fabric. Paracas textiles also included a unique type of three-dimensional embroidery using the crossknit loop stitch to embellish borders with polychrome images. The technique was created with a single cactus spine needle as a continuous form of crossed looping.

The Nazca culture, which followed the Paracas on the south coast in the following Early Intermediate Period (AD 0–500), continued one of the most elaborate weaving technologies ever known, with textiles in double and triple cloth, warp and weft patterning, oblique interlacing, and fine garments woven with both discontinuous warp and weft. Andean loomed textiles are characterized in their tradition of four finished selvedges. Individual finished cloth webs were sewn together to complete a garment and were rarely cut.

Very little is known of north coast weaving during the Early Intermediate Period, the time of Moche cultural development. The few surviving Moche textiles identify a technology principally based in the use of cotton and a narrow backstrap loom like that employed on the south coast. But structurally, Moche textiles are distinguished through the use of fine un-plied cotton yarns in twilled and weft-brocaded structures. Moche tapestry is woven with both cotton and dyed camelid fiber weft over a cotton warp using a noninterlocking weft which creates vertical slits between different color areas. Apparently slit-tapestry was common to coastal cultures both north and south.

Although known for only a handful of large weft-interlocked tapestries or tapestry fragments and triple-cloth narrow bands, the Early Intermediate Recuay culture of the Peruvian north highlands developed a distinctive textile tradition. Recuay tapestries were woven on a wide loom of more than seven feet with a short warp of no more than two feet. Brilliantly dyed red and yellow wool yarns are characteristic of Recuay textiles, and tapestries use the highland weft-interlocked structure which leaves no openings between areas of different color. In the south central Andes, weft-interlocked tapestries uncovered on the Chilean north coast have been attributed to the Alto Ramirez culture of the southern highlands. Alto Ramirez textiles exhibit a decided preference for the use of blue and red dyed yarns almost certainly identifying an ancient source and knowledge of indigo dyeing in the southern highlands.

The following Middle Horizon (AD 500–1000) marks a break with previous cultural development. The Peruvian Huari culture located near the modern city of Ayacucho appears to have controlled the central Andean highlands and coast, while the south central Andes was allied to the site of Tiwanaku. Tapestry was the distinctive Middle Horizon medium woven in slit techniques with cotton on the coast and with interlocking camelid fiber wefts in the highlands. Local, coastal tapestry continued to be woven on the narrow backstrap loom. Highland Tiwanaku and Huari tapestries preserved in coastal desert burials identify the use of the wide loom with narrow warp like that used in Recuay tapestry. Huari shirts were woven in two parts and seamed down the center leaving an opening for the head and neck. The few Tiwanaku shirts discovered in northern Chilean desert cemeteries were patterned with similar images but were woven in a single panel with a neck opening woven through discontinuous wefts. Headgear was always used as an important Andean badge of identity. Huari and Tiwanaku officials wore a knotted hat with four peaks or points on the top. Tiwanaku four pointed or cornered hats created polychrome designs in lark's head knots while similar Huari hats were patterned with knots with tufts of wool pile in each knot.

By AD 1000 the highland centers of Huari and Tiwanaku had collapsed and individual cultures began clearly to establish local identities noted in regional textile styles. Warp-patterned structures such as complementary and supplementary-warp weaves were commonly woven in the following Late Intermediate Period (AD 1000–1450). Textiles are often characterized as having repetitive, small-scale imagery in gauze, painted cotton, weft-brocades, and double-woven fabrics. South coast weavers shaped bags and shirts through the selective addition of warp yarns during the construction process. North coast weavers often wove exotic bird feathers into the cloth, creating shirts and other garments with one face completely covered with feather patterns. During this period coastal weaving especially exploited the full potential of natural native colored cottons which were woven in contrasts of white and natural red-brown, beige, and grey.

The highland Aymara weaving tradition was consolidated in the south central Andes during the Late Intermediate Period after the fall of Tiwanaku. Aymara textiles are characterized by elegantly striped warp-faced shirts, woman's dresses, head cloths, and mantles in natural colored camelid fiber yarns often dyed blue, green, and red.

The Late Horizon (AD 1450–1534) again marks the period when local cultures were brought under highland control, this time that of the monolithic Inca state with its capital at Cuzco in the southern Andes. Inca textile patterns are strictly geometric and nonfigurative and the most valued cloth was weft-interlocked tapestry woven on the wide tapestry loom with a short warp. Some of the best preserved Inca textiles have been discovered as miniature offerings covering gold and silver male and female figurines and left on the tops of Andean mountain peaks from Ecuador to Argentina. Male garments include a tapestry tunic, a mantle, a bag with a carrying strap, and a large feather headdress. Female garments include a large wrap-around dress and a narrow, highly patterned belt. Most of these garments are woven entirely in camelid fiber and are colored with red and yellow dyes.

Following the conquest of the Inca state by European conquerors, European methods of textile manufacture were introduced throughout the Andes. The spinning wheel was adopted for workshop production, and the treadle loom was constructed for the manufacture of yardage to be sewn into non-Andean style tailored clothing. Needle knitting was introduced and is now regularly used for sweaters and knitted caps in local communities. Felting was introduced for wide-brimmed hats which have now become part of indigenous community dress in many regions.

While foreign clothing styles and techniques replaced local garment manufacture in coastal regions, European methods never replaced highland traditions in many indigenous communities in Colombia, Ecuador, Peru, and Bolivia. Today, some areas have maintained camelid-fiber spinning practices using the drop spindle and the backstrap loom or the staked ground loom to produce native four-selvedge garments. Men are the principal weavers in indigenous communities in Colombia and Ecuador, and women weave in Peru and Bolivia. In the southern Andes men weave on the European treadle loom. All community members spin, but spinning is generally considered women's work. Many communities continue to express local identities through handwoven patterns and specific color combinations which are worn daily or for community rituals. Traditional four-selvedged handwoven garments are also worn with European-style vests, pants, sweaters, or skirts in many areas. Some communities have specialized in the decoration of textiles with sewing machine embroidery.

Outside of the Andean region, a few Brazilian tribes and groups living in the Amazonian areas of Ecuador, Peru, and Bolivia, have continued lowland traditions using barkcloth, elaborate feather headdresses, and oblique-interlaced bags and narrow bands, textile traditions which may reflect ancient lowland origins never preserved in these wet regions.

South America continues as the native home to herds of guanaco, vicuna, llamas, and alpacas with an export industry in camelid fiber and manufactured textiles. Peruvian cotton is valued for its luster and is enjoying a revival in interest in native natural-colored cotton yarns.

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Thābit ibn Qurra

BORIS ROSENFELD

Abū'l-Ḥasan Thābit ibn Qurra ibn Marwān al-Ḥarrānī al-Ṣābiʾ (836–901) was a Syrian mathematician, astronomer, physicist, physician, geographer, philosopher, historian, and translator from Greek and Syriac into Arabic. His scientific treatises were written primarily in Arabic and partly in Syriac. He was born in Kafartūtha near Ḥarrān (now Altinbaşak in Southern Turkey) and was a student in Ḥarrān. Ḥarrānians, the descendants of the ancient nation Mitanni in the Hellenistic age, were hellenized, and their ancient religion of star-worship was deeply connected to Greek philosophy. In the Arab caliphate Ḥarrānians called themselves Ṣābians since the Ṣābians religion was one permitted by the *Qurʾān*. Ḥarrān University was founded in the fifth century in Alexandria as a school of philosophy and medicine. After the Arab conquest it was moved to Antiochia and later to Ḥarrān where, under the influence of Ḥarrānian traditions, astronomy and mathematics were taught, and it became a university.

At first Thābit ibn Qurra worked in Kafartūtha as a money-changer. Here the Baghdad mathematician Muḥammad ibn Mūsā ibn Shākir met him and invited him to Baghdad, where Muḥammad and his brothers Aḥmad and al-Ḥasan, the Banū Mūsā, became his teachers. Later he worked at the court of the caliphs in Baghdad and in Surra man ra’a (Samarra) as a physician and astronomer. His position as caliph’s physician allowed him to keep his heathen religion. His son Sinān ibn Thābit and grandson Ibrāhīm ibn Sinān also were mathematicians, astronomers, and physicians in Baghdad.

Thābit ibn Qurra’s contributions to science covered many different disciplines, from mathematics to philosophy. In mathematics, he was a translator or editor of translations of many works of Euclid, Archimedes, Apollonius, Theodosius, and Menelaus. Many of these are extant only in these translations. These translations, together with the geometric treatise of Thābit’s teachers, the brothers Banū Mūsa, and his *Kitāb al-mafrūḍāt* (Book of Assumptions) constituted the so-called “middle books” which were studied between Euclid’s *Elements* and Ptolemy’s *Almagest*.

Two of Thābit’s treatises on parallel lines were first written in Syriac, the first under the title *Ktovo al-hay da-tren surte trishe kad mettapkin al bshir men tarten gonowoto dagʿin bahdode* (Book [in which is proved] that Two Lines Produced Under Angles Which are Less Than Two Right Angles Will Meet). The second is called “the second book on the same topic.” Both these treatises are extant only in the Arabic translations made by Thābit himself. The ideas of these treatises were further developed by Ibn al-Haytham (965–ca. 1050), ʿUmar al-Khayyām (1048–1131), and Naṣīr al-Dīn al-Ṭūsī (1201–1274) and later led to the discovery of non-Euclidean geometry.

Thābit’s *Kitāb fī taʿlīf al-nusub* (Book on Composition of Ratios) was devoted to the theory of compound ratios. This theory later led to the notion of real numbers and to the discovery of differential calculus.

Other work covered such subjects as a simple proof of the Menelaus theorem (the first theorem of spherical trigonometry), mensuration of plane and solid figures, and solutions of different problems of integral calculus. His books contained some proofs of the Pythagorean theorem and its generalization, and dealt with the subject of amicable numbers, in which each number is equal to the sum of the divisors of the other.

In the field of astronomy, Thābit was the editor of the translation of Ptolemy’s *Almagest* and the author of many treatises on the movement of the sun and moon, sundials, visibility of the new moon, and celestial spheres. In his treatise “On the Motion of the Eighth Sphere,” extant only in Latin translation (*De motu octave sphere*), he added the ninth to Ptolemy’s eight spheres and proposed the theory of “trepidation” to explain the precession of equinoxes. The fragments of Thābit’s Syriac *Ktovo d’pulog d’yumoto d’shoboʿo al koukbe shabʿe* (Book on the Subdivision of Seven Days of the Week According to Seven Planets) are extant in Bar Hebraeus’ *Chronography*. In this book the planets are designated by their Babylonian and Greek names; this subdivision was known to Romans and Indians and is the source of the names of the days of the week in many European and Asian languages.

Thābit also wrote books on mechanics and physics. His *Kitāb al-qarasṭūn* (Book on Lever Balance) discusses the conditions for equilibrium of different kinds of levers. In his *Kitāb fī masā’il al-mushawwiqa* (Book on Interesting Questions) Thābit tries to explain the phenomenon of the camera obscura. This attempt was erroneous, but it led Ibn al-Haytham in the *Book on Forms of Eclipses* and al-Bīrūnī (973–1048) in *The Exhaustive Treatise on Shadows* to the solution of this problem. He also studied the problems of acoustics in *Mas’ala fī’l-mūsīqā* (Question on Music) which is an extant fragment of his great *Book on Music*.

In geography and medicine, Thābit revised works of Ptolemy (*Kitāb ṣūra al-arḍ*, Book of the Picture of Earth) and Galen. He was the author of the fundamental *Kitāb al-dhakhīra fī ʿilm al-ṭibb* (Book of Treasure in the Science of Medicine).

In philosophy, Thābit emphasized that integer numbers were abstractions of objects of counting and criticized Aristotle who rejected actual infinity. In his commentaries to Aristotle’s *Metaphysics* he considered the problem of the “first motor” and argued with Aristotle’s opinion that the essence is immobile. Many of Thābit’s treatises are devoted to problems of religion, in which he is critical of both Christianity and Islam.

See also: ►Banū Mūsā, ►Sinān ibn Thābit, ►Ibrāhīm ibn Sinān, ►*Elements*, ►*Almagest*, ►Ibn al-Haytham, ►al-Bīrūnī, ►ʿUmar al-Khayyām, ►Naṣīr al-Dīn al-Ṭūsī

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Timber-Handling Technology in Japan

Conrad Totman

Japan has long been known for the ability of its artisans to construct gigantic, durable wooden structures, lesser wooden buildings of graceful design, and small objects of meticulous craftsmanship. One wonders how they were able to use the trees of their archipelago for these purposes when its topography made logging and timber transport so exceedingly difficult.

Preindustrial Timber Handling

Japan's earliest wood-handling technology was predictably simple. Stone – and later metal – hand axes, adzes, and chisels were used to fell and process tree trunks and bamboo to create rafts, dugout canoes, and plank-walled boats; diverse hand tools, weapons, and other small objects; and post-and-beam buildings lashed together with vine and enclosed with thatch or wattle.

During the seventh century, however, major new architectural forms – grand wooden palaces and Buddhist temples that utilized stone foundations, mortis-and-tenon framing, board walls, and tile roofs – arrived from the adjacent continent. These new forms vastly increased the demand for timber and, as a consequence, produced changes in all stages of wood handling, from felling and transporting to final fashioning into the devices of daily life. In following centuries that technology was elaborated and refined, and its usage spread across the islands.

In the first stage, loggers used slender-hafted, narrow-bladed axes to fell and limb trees and cut them to length. By the sixteenth century blacksmiths were producing large saws with sufficient temper and consistency of thickness for use as crosscut saws, and for several decades woodsmen employed them in felling trees. During the seventeenth century, however, their use for felling was outlawed, evidently to prevent timber theft: the sound of an axe thwack carries much farther than does the swish of a saw, helping guide warden to miscreant. From then until the late nineteenth century felling was handled by professional axmen. To facilitate the felling of especially large trees, choppers gouged holes around the base, stuffed the wood chips back into them, and set them to burning, guiding the burn through the base so as to fell the tree in the desired direction.

Turning to transportation, in early centuries, when adequate timber was available within reasonable proximity of a construction site, logs could be carried to it on two-wheeled oxcarts. Or they could be floated downriver (or hauled upstream by man or animal power), snared and pulled ashore at a landing, and then loaded onto carts for overland transport.

Later, as lowlands were cleared and more and more timber came from steeply mountainous regions, the transport system became more complex. Skidding crews at the felling site used long-handled hooking tools, vine or woven rope, and, where the situation required them, winches and sleds to role, skid, and sled pieces down to a log-assembly point. There (or sometimes at the felling site) axmen hewed the logs to form roughly rectangular pieces. This hewing reduced log weight, rendering sticks more manageable, and it made them more stable for the journey to town. In particular, when used to form rafts, hewn pieces were far less likely to twist and tear apart as raftsmen were negotiating rapids and turns in the river.

Depending on the terrain, workmen might use some of their squared sticks to form log trestles or trough-shaped chutes down which they could slide pieces to streamside. Or in the case of assembly beside a small mountain stream, they could construct splash dams and elevated chutes as needed to propel sticks on the flood down to where normal stream flow would float them freely.

Where felled trees were being converted to shingling or other small pieces, they commonly were split to portable size at the felling or assembly site or at a river landing. And material for conversion to charcoal was processed in kilns and the cooled charcoal bagged for transport. Both split pieces and charcoal were then carried overland to market by packhorse or floated out of the forest aboard log rafts.

The trip by water could be complicated. Most of Japan's rivers rush from mountains down to the sea, and given the frequency and unpredictability of downpours, freely floating logs risked doing damage to riverbanks or facilities, being stranded by high water at inaccessible sites, or even of floating out to sea and being lost. At convenient locations, therefore, river transporters constructed floating booms by lashing bamboo or logs together with vine and anchoring them to rock outcroppings, trees, or huge posts as the site allowed. These booms captured floating sticks, enabling workmen to beach them for temporary storage or processing or to assemble and bind them into rafts for the remainder of their journey.

On the largest rivers, the short initial rafts were beached at a midway point and several then joined end-to-end for the journey's final leg to a landing near the coast. At seaside, especially large logs could be lashed to shipside or hauled astern to a port of destination. But most pieces were taken aboard for the trip.

At the lumberyard or work site, squared logs were left floating in the water until needed, or they were stacked on land for curing and sale or processing and use. To convert a log to boards or planking, sawyers positioned one end on a high A-frame and used wide-bladed saws to rip it to the specified dimensions. The saw teeth were shaped to cut on the draw stroke rather than the push stroke, which reduced the risk of kinking the blade. That design lowered the required level of temper and hence the cost of the saw, but it increased the frequency of sharpening.

Other workmen used regular axes or broadaxes to split sticks into staves, shingles, or fuel wood. And carpenters and craftsmen employed a handsome array of hammers, small saws, adzes, planes, chisels, rasps, and drills to shape pieces for final use, whether as building parts, cabinetry, tools, weapons, *objets d'art*, or whatever.

By the nineteenth century, then, Japan had a well-developed and complex system of wood provisioning. It was operated by an array of professionals – axmen, skidders, raftsmen, other rivermen, sawyers, and carpenters – most of whom were organized in guilds that protected their fields of expertise and employment. And timber merchants, who arranged and financed many of the logging and transport operations, also managed the lumberyards and handled most of the wholesaling, jobbing, and venture capitalization that the timber business entailed (Figs. 1–3).

Industrial-Age Timber Handling

The world of preindustrial timber provisioning was thrown into turmoil during the 1860s when the established political order collapsed in the face of foreign encroachments. The new rulers set out to achieve rapid national self-strengthening, and that project entailed, among other things, sharply intensified exploitation of domestic resources, woodland included. Those developments altered radically the techniques of felling, transporting, and milling timber.

Until around 1900 the organized guilds of axmen, raftsmen, and others were able to slow appreciably the inflow of new technology. But by then the use of crosscut saws – no longer forbidden after 1868 – had become common, and they prevailed into the 1950s, until being displaced by chain saws. And in those areas, mainly in Hokkaido, where tractor-mounted mechanical saws are able to function, they and other similarly "high tech" devices – feller-bunchers, skidders, processors, harvesters, forwarders, and tower yarders – have been introduced during recent decades in unsuccessful attempts to reduce labor costs enough so that the domestic timber harvest can compete with imports.

Timber-Handling Technology in Japan. Fig. 1 Stacking wood at a lumberyard on Tatekawa Canal in a harbor side section of Edo (today's Tokyo). Men on the left stack split pieces of fuel wood; bales of charcoal are stored under thatch cover at their feet; sawyer on right rips a timber to form planks; poles are stacked vertically to his right, partially obscuring Mt Fuji; planking, boards, squared timbers, and long green bamboo poles are below him. (Katsushika Hokusai, *Thirty Six Views of Mt. Fuji* (ca. 1820), in the author's possession.)

Timber-Handling Technology in Japan. Fig. 2 Sawyers rip a squared timber at Yamanaka in Tōtōmi Province, southwest of Mt Fuji, while another workman, seated before their temporary mountain hut, sharpens his saw, as family members look on. (Katsushika Hokusai, *Thirty Six Views of Mt Fuji* (ca. 1820), in the author's possession).

Timber-Handling Technology in Japan.
Fig. 3 Surrounded by his mallets and bamboo for hooping, a barrel maker smoothes the inner surface of his staves at Fujimigahara in Owari Province, west of Mt Fuji. (Katsushika Hokusai, *Thirty Six Views of Mt. Fuji* (ca. 1820), in the author's possession).

Rather similarly, raftsmen and rivermen retained their roles until around 1900, when timber began leaving the forest by tramway and railroad. By the 1930s nearly all flotation and rafting had ceased. But starting then, and especially after 1950, rails in turn gave way to roads as trucks and "Caterpillar" type tractors and sleds took over. In some interior valleys, moreover, highlines have come into use for carrying logs airborne from felling site down to assembly point, where they are yarded and loaded onto trucks or otherwise moved along for processing.

Sawmills had appeared in Japan by the 1870s, initially sash saws (vertically mounted, mechanically powered crosscut saws), subsequently circular saws, and eventually band saws (continuous ribbons of teethed steel driven at high speed by sheaves mounted above and below the saw carriage). The earliest were water and steam powered, but electric power, whether purchased or produced on site, came to prevail during the early 1900s. And internal-combustion engines later powered some portable mills. (Pulp, plywood, and chip mills, technologies that are not discussed here, were introduced to Japan, respectively, in 1886, 1907, and 1957.)

The scale of Japan's sawmill technology has differed greatly from that found elsewhere. During the years ca. 1860–1920 the productivity of mills in Euro-America rose dramatically, tenfold or more. That rise was made possible by myriad technical improvements in saw types, power sources, and other aspects of mill equipment. But it also was premised on two conditions not found in Japan.

First, it presumed the existence of sprawling, richly stocked, flatland forests cut by leisurely flowing rivers that could float vast quantities of large, same-species logs to a sprawling sawmill site, flatland that would, a few decades later, provide easy terrain for the construction and use of roads and railways. Second, it presumed a system of woodland ownership that would allow a mill to obtain vast quantities of logs from large, more-or-less contiguous areas. In Japan, however, nearly all forests were on steep mountainsides, and possession was highly fragmented, about half being owned by smallholders with a few acres apiece, the other widely scattered half by government. Almost nowhere could a mill operator expect to obtain substantial quantities of large-scale timber from his immediate environs for any extended period. In consequence, before World War II the most efficient technology did not fit Japan's circumstances, and the newest devices, band saws most importantly, were used in only a small portion of the country's sawmills.

During the first two decades after that war, great effort was made to introduce and refine the most up-to-date mill technology. However, from about 1970 onward, imported wood undermined the profitability of domestic milling, and the enthusiasm for technological change largely evaporated. Instead, sawmills gradually developed in two directions. Today large, highly integrated mills, which are set up at coastal sites near major markets expressly to handle imported logs, use elaborate, efficient, high-speed equipment to produce great volumes of lumber. Domestic timber, meanwhile, is mostly sawn at small mills set up in major timber-producing areas, where they use much simpler equipment to turn out high-grade, specialty lumber, but at rates comparable to those of American sawmills of the 1860s.

So today the timber-processing technology of Japan is used primarily to handle imported wood. And that situation seems likely to prevail for a few more decades, until destruction of the world's woodland drives global timber prices up enough to make Japan's mountain forests again competitive in the marketplace.

See also: ►Forestry in Japan

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Time

Henry J. Rutz

The dual classification of cultural systems of time as Western or non-Western is an oversimplification that limits our understanding of how time is created, represented, measured, and practiced in different cultures. The premises underlying dualistic thinking about time reveal its limitations.

First, dualistic thinking adopts the premise that Western time is linear (irreversible), abstract, quantitative, and homogeneous. In contrast, non-Western time is cyclical (reversible), concrete, qualitative, and heterogeneous. There is a tendency to draw too sharp distinctions based on characteristics presumed to be in opposition. Underlying these are further distinctions between *them* (Oriental, primitive, oral, preindustrial) and *us* (Occidental, modern, literate, industrial). Embedded in these implicit distinctions is the assumption that non-Western time is to be thought about within a conceptual frame that implicitly adopts Western time as a standard for perception and evaluation of non-Western time. In a word, dualistic thinking about time has been Eurocentric.

Second, dualistic thinking rests on the premise that Western and non-Western cultures are different and unrelated totalities, and that time is unitary within each. The Unitarian premise leads to generalizations such as believing that non-Western cultures have a cyclical as opposed to a linear concept of time. The result is that diversity is underreported and undertheorized.

Third, dual systems of culture and time suffer from an ahistorical and overly formal foundation to knowledge. Western societies have "history" and a consciousness of being in time, in contrast to non-Western societies which have "myth" and a sense only of relational time that renders events mere epiphenomena of structure. Myth is not about the causation of before and after but about a formal means for making all the elements and characters ever-present.

Fourth, the ahistoricist premise also leads to the view that non-Western societies have an awareness of themselves in time only to the extent that westerners bring such awareness to them, either in the form of historical consciousness or as a practical matter of the efficient and productive use of time as a resource.

Fifth, dualistic thinking rests on the premise that time is a thing that is either present or absent in a culture. A dichotomy between western *linear* time and non-Western *cyclical* time appears as real and coerces people to behave and think in a particular way. But the terms of this dualism are highly abstract and refer to no particular period, bounded space, social organization, or real people. The dichotomy bears little relation to the cultural construction of time in the everyday lives of people in a specific region, a particular period, or known conditions of migration, diffusion, and contact.

The situation is complex. While no cultural constructions of time have remained unaffected by European expansion, it is presumptuous to think that we know what aspects of European time (which varied in different periods and places) influenced a bewildering variety of religious communities, empires, and kin-ordered societies, each with its own historically constituted temporal rhythms. Indeed, examining the real complexities of culture and history raises important issues about temporal dynamics only to the extent that we abandon dualistic thinking.

An alternative perspective, one that anthropologists, historians, and archaeologists increasingly embrace, pays attention to multiple constructions of time in single social formations, the extent to which different times are articulated, and the temporal dynamics of development and change in the rhythms of everyday life.

While some languages lack a generic word for time, there is abundant evidence for the universality of concepts of duration and succession in the linguistic and cultural practices of every person. The French sociologist Émile Durkheim expressed the opinion that it is hardly possible to think about time "… without the processes by which we divide it, measure it or express it with objective signs." These processes, he concluded, are social in origin. The anthropologist Edmund Leach, following Durkheim's lead, noted that "We talk of measuring time, as if it were a concrete thing waiting to be measured; but in fact we create time by creating intervals in social life. Until we have done this there is no time to be measured." To these ideas about time we need to add those of another French sociologist, Georges Gurvitch, who pointed out that every social formation has a multiplicity of times. Not only are there different collective representations of time among different cultures, but different time systems coexist within a single social formation.

These ideas, that time is culturally constructed, socially embedded, and multiple, have become guiding principles in cultural studies of time. The other articles on time in this encyclopedia illustrate the complexity and diversity of time systems from the multiplicity of time perspective. A brief comment on a number of issues will clarify the present direction in cultural studies of time systems.

1. Acceptance of the multiplicity of time within single social formations has led to the rejection of attempts to classify whole societies, not to mention a whole class of societies such as "Western" or "non-Western" by any single subsystem of time. Comparison remains important, but comparativists now

recognize that they must seek out similar subsystems in different cultures. Leopold Howe, for example, disputes Clifford Geertz's conclusion that the Balinese calendrical system does not represent a flow by which the passage of time can be measured, that the calendar represents a concept of time that is nondurational, and that Balinese experience of time is of "islands" or points that are unconnected (an extreme form of discontinuity, imprecision, and noncountability). Geertz asserts that the particulate nature of days implies a nondurational concept of time. Such a description of Balinese time carries an implicit comparison with our own, based on dualistic assumptions that go unexamined in both. Howe provides evidence that Balinese count days and are forever referring to past and future in terms of such counts. Geertz confused an attribute of members of a class with the class itself—each day is qualitatively different from others, but days fit into a succession that is endlessly repeated. Each name day partakes of being a day that *qua* day has the attribute of countability. The Maya had no such confusion. They viewed time as a flow that could be measured and also endowed days with qualities dependent upon the work of gods and men.

2. Recognition of the multiplicity of time shifts attention away from gross comparisons of presumed-to-be-different systems of time toward contextualized descriptions and similarities of subsystems in apparently different cultures. There has been a concomitant shift from classification to process, raising questions about temporal dynamics. How *does* time get constructed? What *are* the processes of development and change that account for the multiplicity of time and the degree of articulation among subsystems? Cultural studies of time have taken several directions, none of which is mutually exclusive. Nancy Munn challenges, from a phenomenological perspective, Evans-Pritchard's conclusion that Nuer time amounts to a creation of a static and nondevelopmental experience of time. His structural models of Nuer time overlook Nuer accounts of their bodily activity of procreation, their own subjective experience of time in terms of layers of ash on the fires, their ability to plan for events in the future, and other evidence of developmental constructs of time in their projects and practices. Peter Rigby, who has researched the age-set system of the pastoral Ilparakuyo Maasai in Kenya, challenges, from a historical materialist perspective, Evans-Pritchard's failure to address the degree of articulation of Nuer multiplicity of time. Had Evans-Pritchard taken into account the historical consciousness of Nuer, he would have found that all the elements of time-reckoning can be placed in a single conceptual frame arising from the historical development of Nuer within a specific social formation. Rigby, drawing on his own work and that of others, attempts such a synthesis for the Ilaparakuyo Maasai.
3. Cultural studies of time that explore the underlying temporal dynamics of how a multiplicity of time is constructed have paid increasing attention to the politics of time. Cultural constructions of time are part of the political economy of development. The creation of time requires agents and agencies temporalizing their respective projects in struggles for power and legitimacy. Farriss' attempt to reconcile cyclical and linear concepts within the same calendrical system in Maya culture rests on an interpretation of Maya political transformation from city-states to rule by dynastic lineages. With the demise of Maya elites, subsystems of time wither and die.
4. The attention paid to the politics of time has raised anew issues about the reflexive study of time in different cultures. Johannes Fabian has criticized anthropologists for failing to recognize that theories which distance "other" cultures by placing them in an-other time unwittingly use time as an instrument of political domination. Apparently disinterested studies of difference are revealed to be interested studies of "the other", a form of cultural politics. The solution is to recognize that people of different cultures are contemporaries and use that as a point of departure for all conceptual frames concerning the politics of time. A reflexive approach to cultural construction of time would overcome Rigby's concern that most descriptions of time in "different" cultures are really implicit comparisons using hegemonic bourgeois time as a standard. Most of us reckon time in our daily lives by systems other than the formal-mathematical or chronological ones deployed by an army of scientists, historians, and anthropologists. Such reflexivity, or self-awareness, of our own multiple concepts of time would be salutary for advancing our understanding of the cultural construction of time in different cultures.

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Time in Africa

HENRY J. RUTZ

In every society, one source by which time is divided, measured, and expressed by objective signs is the mutual obligations and principles that structure social relations between persons and groups. Among the most important is kinship. In those societies in which kin communities encompass the widest range of social relations, time is expressed as duration and succession of kin-ordered activity. Perhaps the best-known case is that of the Nuer, a Nilotic pastoral people who live in villages of the upper reaches of the Nile in Sudan.

E.E. Evans-Pritchard has given us a rich account of ways in which village kin communities conceptualize and reckon time as an aspect of social structure. Among the multiplicity of times apprehended by Nuer, three of the most important subsystems are (1) a series of social activities articulated with a series of ecological events by which one is used to measure the duration and succession of the other; (2) a series of age-sets that measures intervals and succession in the life cycle; and (3) a hierarchy of segmented kin groups that measures lapsed time, i.e. a form of collective memory of the "past" that constitutes the conceptual frame of Nuer history.

Nuer livelihood is based primarily on cattle herding and the cultivation of millet, a dual adaptation to vast stretches of marsh and savannah in a climate that necessitates a transhumant existence between village settlements on knolls during the rainy season and dry season cattle camps near rivers. A change of season is the objective sign for a change in settlement pattern, accompanied by changes in ceremonial and social activities. Most collective rituals, such as marriage and male initiation, take place in wet season villages, but the dry season cattle camps, when youth disperse to small camps in search of pasturage near sources of water, are viewed as a time of freedom and courting. In a rare comment on the experience of seasonal rhythms, Evans-Pritchard states that the pace of time speeded up during the wet season and slowed down during the dry season, an effect of the density of social activities and the significance the Nuer attributed to them.

Although the Nuer have no word for a generic "year", they reckon cycles of wet and dry seasons, giving names to each, and divide the cycle into twelve named "moons" of unequal duration that mark the succession from wet to dry season and back again. The duration of months depends less upon lunar observance (though they are familiar with phases of the moon) than the agricultural and pastoral activities associated with ecological phases within seasons. Nuer adjust the series of ecological activities to fit social contingencies. If the Nuer were still in their dry camps, waiting for rain, then they would say that they were still in the named "moon" prior to the onset of rains. If they were still engaged in rituals associated with the wet season villages, then they would reckon the name of the moon by the social activities appropriate to it. The result is an annual calendar embedded in a coordinated parallel series of ecological and social rhythms, the durations of which vary within and between cycles. Working one series against the other, Nuer rename months, skip months altogether, or even omit "years" in their recounting of socially significant events over a number of seasonal cycles.

Nuer can count seasonal cycles, months, and days (there is no "week"), but they tend not to. Chronology or a sense of lapsed time with respect to livelihood is culturally suppressed, giving the illusion of endless recurrence. Days, months, and seasons remain socially embedded and unarticulated as an abstract and numerical system independent of the concrete activities that lend the system meaning. The Nuer have no generic word for time.

Biological facts of individual maturation and aging, like ecological and physical facts, are given social significance in every society. But their division, measurement, and expression in objective signs are contingent and vary from one society to another.

Among Nuer, the reproduction of cattle, or cattle genealogies, is the basis of a concept of male personhood. Individual Nuer men are fiercely egalitarian and quick to defend themselves against perceived affronts to their manhood. The natural reproduction of cattle, combined with a culturally constituted series in the life cycle of male individuals—for example the transition from boyhood to manhood marked by the gift of a first cow, the transition to husband marked by a gift of cattle at marriage (a transfer from the groom's to the wife's kin), and a further transfer of cattle marking the transition to "fatherhood" with the birth of each successive child — regulate the rhythms of interpersonal kinship, articulating the pedigree of specific cows with the genealogy and life history of individuals.

Cattle genealogies mark the passage of time in the lives of individual male Nuer, a process that in its very nature is directional and irreversible. But Nuer also have organized individual male maturation as a collective problem of social significance. Village boys of comparable age (between 14–16 years) are initiated into a named age-set during an open period. A “Man of the Cattle” is responsible for closing a period, “thereby dividing the sets.” The initiation consists of a painful ritual whereby each boy is cut to the bone across the forehead six times, producing deep scars called *gar*. His reward is a gift of his first cow and a taboo on milking. The only point of articulation between the seasonal and age-set time systems is the timing of the initiation, which occurs at the end of the wet season when food is plentiful. Proximate villages tend to coordinate periods despite independent declarations in each. Regions tend to share at least some age-set names (but vary the sequence), which differ from one part of Nuerland to another.

In pastoral Kenya and parts of Bantu East Africa, the age-set/generation-set system consists of age-sets organized into three distinct generation-sets of boys, warriors, and elders, with a pronounced taboo on warriors marrying. It is hard to avoid the conclusion that Nuer age-sets have something to do with the collective control of elders over young men. The military and administrative functions of Nuer age-sets, however, are attenuated and appear to have more to do with regulating the domestic obligations of manhood.

Nuer conceive of the age-set system as fixed at six living sets. Using a kinship idiom, they break the sets down into “brothers” who are equals, “fathers” who are elders in authority, and “sons” over whom they have authority. But age-set names are not repeated and Nuer do not perceive the age-set system as cyclical (some Bantu groups do). Age-sets whose members have died are not remembered or recounted. Even when a few old men of the most senior age-sets are still alive, junior age-sets are merging them with members of adjacent age-sets. The system is designed for the living, intended to mark lapsed time by the intervals between open and closed periods that define the age of one group of males relative to another in a weak form of gerontocracy. Like individual biography inscribed in cattle gifts and their genealogies, a sense of an irreversible flow of time is given in the fact that a named age-set “changes its position in relation to the whole system, passing through points of relative juniority and seniority.”

All human communities develop collective representations of a past that embody a historical consciousness of the community *qua* community. Nuer have embedded their sense of historical consciousness in a model of a lineage system that creates the illusion of a fixed temporal horizon to events such as migration, tribal war, and territorial expansion that might otherwise be perceived as a succession of unique events in an irreversible “before and after” construction of past and future. The correct view of Nuer history is that it is ever-present and performative in the reciprocal rituals of lineage segments.

The segmentary principle of membership in a Nuer lineage is common descent through males from a recognized ancestor. The way Nuer think about tribal history is structured by how they think about the hierarchical relations between lineages, which also form the basis for claims to a division of territory. Reckoning political relations by lineages is relative because it depends on the particular person who is selected as the point of departure in tracing descent. The largest lineages, those which incorporate the widest latitude of members connected by descent from a common ancestor, are termed clans, and they in turn are comprised of lineages with several lines, each of which is a smaller lineage tracing descent through less distant ancestors to incorporate a narrower range of members.

The lineage system is employed by living Nuer to reckon their common past. Although every man is a potential founding ancestor, the social fiction is that the living are organized into segments in such a way that there are only ten to twelve ancestors at the maximum social distance, and three to four at the minimum. This fixed system of reckoning is in contrast to the real events of Nuer history, which is one of human propagation inscribed in Nuer genealogical reckoning, expansion and contraction of territory, and the actual bifurcation and amalgamation of lineage segments. But the Nuer fit such events into a structure of lineages with a time depth of 10–12 generations when there is no reason to presume that they have existed for so short a time. The Nuer express their political history as a fixed structure of relations between lineage segments. They prefer a stylization of history to a record of the endless march of unique events in an irreversible flow of time. The absence of writing and the strength of oral culture no doubt have something to do with it. The content of relations changes and is irreversible, no matter who the ancestors are or where a particular named unit fits into the hierarchy, but the structure remains constant. Eternal returns, with their prophecies of foretelling and fulfilment, or dynastic genealogies that record the unfolding succession of heroic deeds from some fixed starting point into a receding time horizon, are not the stuff of Nuer social history.

The Nuer are a tribal state without centralized authority. Their kin-ordering and genealogical reckoning are the key to their construction of time, which contrasts greatly with that of empires. In those states where imperial elites (military and religious) ruled over vast areas and innumerable village communities from imperial centres, there developed an awareness of time itself as an objective instrument of power and legitimation.

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Time in China

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Chinese methods of calculating time are of great antiquity. According to the *Shi Ji* (Book of Records), as early as 2254 BCE Emperor Yao employed astronomers to calculate solstices and equinoxes and predict seasonal change so that farmers would know when to plant crops. Oracle bones dating to ca. 1200–1181 BCE attest to the fact that Shang Dynasty Chinese calculated time using a 60-day divinatory calendar that still is in widespread use. The early development of methods of measuring time was not entirely endogenous to China; cultures throughout the ancient world exchanged astronomical ideas and data.

Striking similarities exist between calendrical systems in widely separated regions, including parallels between the form and names of the Chinese and Maya divinatory calendars. At least as early as the first century BCE the Chinese used a luni-solar calendar resembling the standardized Babylonian calendar developed in the fourth century BCE. The similarities suggest borrowing, and it is possible that the Babylonians were the original inspiration for the Chinese soli-lunar calendar. In the Sui and Tang dynasties (589–960), Indian astronomers resided in China, and during the Yuan dynasty (1280–1368) Chinese collaborated with Persian and Arab astronomers. The technology of observation and measurement included an observatory built in Beijing during the Yuan dynasty. Contrasting with the astronomical system developed in Greek and medieval European astronomy, Chinese astronomy was polar and equatorial rather than ecliptic.

Although at times the Chinese borrowed astronomical ideas and technologies, these became incorporated into a system of time reckoning rooted in Chinese society. Sociologists have observed that time is a symbolic structure that represents a society's collective rhythms. In the Chinese calendar, some elements are based on astronomical cycles, while others have been shaped by the temporal rhythms of social life.

Chinese notions of the seasonal cycle are integrated into a system of classification based on the dualism of *yang* and *yin*. While *yang* and *yin* are often defined in terms of the complementary dualism of male and female, in Chinese they originally referred to sun and shadow, the very elements used to measure the changing seasons. For Chinese metaphysicians, *yang* and *yin* came to denote primal cosmic forces that interacted to generate a cycle of five phases (*wuxing*) which were identified with five primary elements (wood, fire, metal, water, and earth). These phases and their associated elements were in turn identified with the seasons. Thus Chinese classified spring with wood, summer with fire, autumn with metal, and winter with water, while earth was associated with the midpoint of the year.

This model of cyclical process associated the five phases with five colors (green, red, yellow, white, and black), directions (east, south, the center, west, and north), organs of the body, tastes, planets, virtues, passions, etc. Chinese elaborated rituals designed to control this cyclical process. Throughout the yearly cycle, the Emperor performed rites to inaugurate the seasons, and his performance gave concrete expression to the association of season, direction, color, and ritual. Chinese thought that by means of these ritual performances, the emperor could ensure harmony in the universe, and interpreted natural calamities as evidence of his loss of the "mandate of heaven" (Granet 1934). The cosmological framework of *yin* and *yang* and the five phases also informed Daoist alchemy, and still is fundamental to the Daoist rituals of popular religious culture.

Chinese philosophers and scientists appreciated the importance of natural cycles, and also linked the cycles of time with the cycles of human life. Not only they did link cyclic ideas of time to the liturgical calendar that regulated rites performed in the imperial court and its temples, but also they linked it to the microcosm of the body. In contrast with the taxonomic thinking that informs much Western science, Chinese explored patterns of function *through* time to make sense of various experiences, including ones related to health and illness. The associations of the five phases applied not only to the yearly cycle, but also to the cycle of the month and the day. For example, Chinese medical practitioners thought that the "seasons of the day" could predict crisis periods for physical disorders affecting different parts of the body.

While cyclical time had key significance, Chinese also had a well-developed concept of continuous time.

This concept found expression in "continuity history-writing," in which historians sought to chronicle causal sequences of events in history. While official historians recorded the objective facts of history, they also critiqued the past in a form of "praise and blame" historiography that sought to discern the logic of a *Dao* (path or way) that had its origins in Heaven. Thus the rulers of China employed history, like divination, as a means to gain insight into the logic of events, and as a guide to appropriate action.

In an agricultural society, charting seasonal change was crucial, and one responsibility of the emperor was promulgation of the luni-solar calendar. Since promulgation of a calendar was a political responsibility and privilege, astronomy was an orthodox Confucian science. Every year a Board of Mathematicians led by an Imperial Astronomer (who was a Minister of State) prepared the calendar. After the Emperor approved the new almanac, high-ranking officials received it with great ceremony. The Emperor, who had exclusive rights to promulgate the calendar, also bestowed the almanac upon China's vassal states as a mark of favor. During the Qing Dynasty (1644–1911) over two million almanacs were officially printed each year, and excess copies were available for sale. Despite this imperial monopoly, pirated editions circulated widely. Rebellious feudal lords sometimes expressed their withdrawal of allegiance by issuing a new calendar.

The Chinese used the calendar as an instrument to predict not only the best time for planting, but also the best time to initiate action. As a consequence, astronomy was interwoven with astrology and divination. Details of the zodiac are still published in the almanac, and the Chinese may consult this source to predict dates that are propitious or unpropitious for human undertakings such as weddings.

The most ancient method of timekeeping is the 60-day divinatory calendar, evidence for which appears on oracle bones in the late Shang dynasty (ca. 2300–1181 BCE). The cycle is composed of two interlocking sets of cyclical characters that are combined to form 60 unique two-syllable names. The "Ten Heavenly Stems" (*tian gan*) revolve in concert with the "Twelve Earthly Branches" (*di zhi*), and their combination generated 60 cyclical names. These 60 combinations were arranged in six 10-day groupings called *xun*. Since the first century BCE, years have been named after the consecutive days of the divinatory calendar, producing a repeating 60-year cycle. In the late Shang dynasty, the *xun* of the dyadic divinatory cycle was the basis for ordering sacrifices to royal ancestors. A full ritual cycle was completed in 360 days, increased to 370 by the addition of an intercalary *xun* every second cycle. This arrangement created a calendar that approximated the length of a solar year.

The Twelve Earthly Branches correspond to the 12 signs of the Chinese Solar Zodiac, which also name 12 constellations used to calculate the position of the sun every month. The zodiac animals (six wild or mythical and six domestic) are the rat, ox, tiger, rabbit, dragon, snake, horse, sheep, monkey, cock, dog, and pig. They are divided between passive *yin* and active *yang* symbols, and name the years in a repeating 12-year cycle. Chinese popular wisdom has it that persons who are born in a particular year have personalities shaped by the associated zodiac animal. Individuals should avoid marriage with persons born in the zodiac years of antagonistic animals, and also seek to avoid having children during such years.

The task facing early astronomers who sought to invent a calendar for use in predicting the seasons involved reconciling lunar and solar cycles. The regular cycle of the moon provided a readily observed celestial clock, but the lunar year does not correspond with the seasons, since 12 lunar months produces a cycle of only 354 days. The yearly cycle of the sun produces a cycle of 365 1/4 days, but it does not predict the full moon. The 365-day Gregorian calendar follows the solar year alone, with an extra day added every leap year to adjust for the fraction. The Chinese, however, sought to reconcile solar and lunar calendars.

By the eighth century BCE, Chinese could calculate and record eclipses, and they knew of the Metonic Cycle. This was a 19-year cycle at whose beginning and end the sun and moon are in the same relative position to each other. Discovery of this cycle led to a system of coordination of lunar and solar cycles that resembles the Babylonian standardized calendar, and some authors have suggested that this system was perhaps borrowed rather than invented (for details of debates, see Needham 1959: 171–177).

During 19 solar years, there were 235 lunar months, and Chinese astronomers divided these into 12 years that were 12 lunar months long, and 7 years that were 13 lunar months long. The 13-month years were produced by duplicating 1 month. The inventor of this calendar introduced that intercalary month in such a way as to ensure that the winter solstice always occurred in the eleventh lunar month, the summer solstice in the fifth, the spring equinox in the second, and the autumn equinox in the eighth. In addition, the introduction of an intercalary month ensured that the Chinese New Year always fell on the second new moon after the winter solstice, between January 20th and February 19th.

Before the adoption of the luni-solar calendar, Chinese dynasties inaugurated their reign by adopting a different month as the beginning of the civil year. The Manchus are said to have followed this tradition when Emperor Kang Xi in 1669 adopted the revised calendar proposed to him by the Jesuit Father Verbiest. The Republican Government expressed its break with imperial rule by adopting the Gregorian calendar, which was favored because of its universality. Its adoption also eliminated a powerful source of imperial authority, since monopolistic control of the calendar contributed to a mystification of Manchu power. None the less, the traditional luni-solar almanac still regulates the cycle of community festivals and the rituals of ancestor worship.

See also: ►*Yin–yang*, ►Five Phases, ►Geomancy in China, ►Astrology, ►Lunar Mansions, ►Calendars, ►Stars in Chinese Science, ►Divination in China

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Time in Islam

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Islam is now a major global religion. It has its roots, however, in the Arabian Peninsula of the early seventh century. Its core elements were implanted in the early years and all later developments relate, one way or another, to that core.

In pre-Islamic Arabia some elements seem to have related to time (*dahr*) as fate, an underlying force directing human and natural destiny. It was conceived as a power existing eternally and responsible for the happiness or agony of humanity. Thus the *Qurʾān* refers to those who "say… 'nothing but time can destroy us'." [45:24/23]

While time was generally seen as an impersonal force, some people sought to identify God with time or, worse still by Islamic standards, to use this concept to deny God's existence. The Apostolic Tradition (*ḥadīth*) records Muḥammad's saying that Allah commanded men not to blame *dahr* "for I [God] am *dahr*." Later there were various groups of radical thinkers, often only vaguely defined and known primarily from polemic references, who asserted "the eternity of the course of time." Accordingly, because they denied both Creation and Judgment, the beginning and end of time, they were considered atheists. The term *dahrīya*, therefore, came to encompass a broad spectrum of dissenters advocating some form of atheism and/or hedonistic materialism.

Islam universally views time as created. It is God's handiwork which, like all Creation, is under God's command. God acts in and through history but, being eternal, time does not encompass him. Nature is also his Creation but, while it manifests his greatness, it in no way encompasses Allah.

According to al-Bayḍāwī (d. 1282) in the *Anwār at-tanzil wa-asrār at-taʾwīl* (The Lights of the Revelation and the Secrets of the Interpretation), time consists of *mudda*, the period of revolution of the sphere from beginning to end (i.e., the totality of time); *az-Zamān*, a gross subdivision of *mudda* into long periods of time (e.g., specific historical eras such as dynastic reigns); and *al-Waqt*, a fine subdivision of *zamān* into definite points of time or short intervals (e.g., precise times of the five obligatory prayers).

There are some within the Islamic tradition who assert that time, begun at Creation, has no necessary end. Al-Ghazālī (1058–1111), speaking in the *Tahāfut al-falāsifah* (Inconsistency of the Philosophers) for the mainstream tradition, teaches that religious dogma, for example the Day of Judgment, points to a finite end to time.

Measurement of Time

The two most significant historical eras, in the consciousness of Muslims, are the Age of Ignorance (*al-Jāhilīya*), the Dark Age in Arabia before the revelation of the *Qurʾān*, and the Islamic age stretching from the formation of the Islamic community in AD 622 until the end of history at Judgment.

There is evidence which suggests that most ancient Arabs followed a pure lunar calendar. About two centuries before the Prophet, apparently under the influence of Jewish civilization, many in Arabia adopted a lunisolar calendar. After Muḥammad's transfer to Medina (the *hijra*), an absolute lunar calculation was mandated.

The *hijrī* year consists, in theory, of 12 months of 29 days, 12 h, 44 min, and 3 s. In fact, for various practical reasons, the lunar months are computed variously as having either 29 or 30 days. The *hijrī* year is about 11 days shorter than the solar year. There is no intercalation to the solar. Any particular *hijrī* date, over a period of approximately 33 years, will move through all four solar seasons.

A number of Islamic societies have introduced a solar or lunisolar calendar (e.g., pre-revolutionary Iran, Kemalist Turkey). None of these has achieved any universal acceptance among the world's Muslims. It is accepted, further, that such a calendar has no support in the *Qurʾān* or the prophetic *Sunnah*.

Specific points in the yearly cycle are sanctified and celebrated in various ways. There are many local holidays and celebrations, and certain times are acknowledged as primary Muslim holy times. The first is the month of Ramaḍān during which the Muḥammad's prophetic career was begun. For the entire month Muslims abstain from food, drink, smoking, and sexual contact. The fast begins each day at the moment that there is sufficient light to distinguish white from black threads. It ends each night after the sun has completely set. Islam's "lesser feast," *ʿId al-Fiṭr* (breakfast), brings release from the month-long abstention.

The "greater feast" is the *ʿId al-Aḍḥā* (Feast of Sacrifice) on the tenth of Dhū 'l-Hijjah. It celebrates the end of the Holy Pilgrimage (*Hajj*) and reenacts Abraham's sacrifice of a ram in place of his son (*Qurʾān* 37:102). The primary sacrifice is made by the pilgrims in the valley of Minā, near Mecca. Muslims all over the world also offer such a sacrifice.

In Muḥammad's time the Arabs counted a 7-day week. There is evidence that this is a relatively late practice imported from Babylonia (or, perhaps, by way of resident Jewish communities who observed the weekly Sabbath). Earlier time flow was divided according to weather and similar seasonal changes. Under Islam the week was given significance by assigning a special status to Friday. It is not a day of rest but rather a day of communal prayer.

Time as a Moral Dimension

> By [the token of] Time [through the Ages].
> Verily Man is in loss.
> Except such as have faith and do righteous deeds and
> [join together]
> in the mutual teaching of truth and of patience and constancy. (*Qurʾān* 103: 1–3)

There are numerous Quranic references to man's time and God's time. "He rules [all] affairs from the heavens to the earth: in the end will [all affairs] go up to Him, on a Day, the space whereof will be [as] a thousand years of your reckoning [32:5]." Creation, as well, is said to have been effected in 6 days [32:4]. Exegetes often emphasize that the days of Creation, before the placement of the sun, refer to God's days reckoned as a thousand man years (and, in 70:4, to 50,000 years). Muslim scholars reiterate that Allah is in no way bound by time; he is totally transcendent.

The point is that throughout the course of human history God maintains full control over his Creation. In his mercy Allah provided man with a window to his will and commanded him in the straight path. When time ends, at Judgment, man will face his time compacted to God's scale. "… In the immense future all affairs will go up to Him, for He will be the Judge, and His restoration of all values will be as a day or an hour or the twinkling of an eye; and yet to our idea it will be a thousand years" (Yūsuf Alī).

There is an implicit ambivalence as regards the pursuit of scientific and technological knowledge. In so far as the Muslim centers his consciousness on God, his greatness and omnipotence, he can easily succumb to a fatalistic acceptance of what comes to him. He then asserts God's absolute will and denies causality in nature. Without cause and effect there is no necessary natural order. In so far as man sees time as his sphere of action, he can hear the Quranic command to perceive God in his Creation. Exploration of the world becomes an act of moral compliance.

Time's purpose is to serve as an arena of moral action. It is the place which God has established for the exercise of will. Judgment and consequent assignment to paradise or hellfire will mean the end of time, its sole purpose being the setting for man's surrender.

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Time in Korea

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Timekeeping was both a royal duty and a royal prerogative in Korea since the period of the Three Kingdoms (三國時代, ca. 37 BCE to 668 AD) of Silla, Baekje, and Goguryeo. Although sundials and clepsydras (water clocks) were the main timekeepers, there were also fire clocks such as incense sticks at temples. Chinese calendrical systems, instruments for astronomy, and timekeeping systems were introduced to the Korean peninsula in antiquity, while from 554 AD Baekje sent calendrical scientists to Japan to supervise calendar- and clock-making there. Among the achievements of such missions was the water clock of the Japanese emperor Tenji (r. 661–671) which was made in 671. In Gyeongju, the capital of Silla, a royal observatory known as the Cheomseongdae (瞻星臺) was built in 647 and a water clock was constructed at the temple Hwangryongsa in 718; the latter was used to announce time by striking large bells in the bell tower, as was the case also with the bell shown in Fig. 1.

Late in the fourteenth century, the rulers of the Goryeo dynasty (918–1392) adopted Guo Shoujing’s *Shoushili* (授時曆, Time-Giving Calendar) that was compiled during the 1270s in Yuan China. They also introduced Su Sung’s astronomical clock tower powered by water and described in the *Xinyixiangfayao* (新儀象法要, The Appearance, Methods, and Importance of New Instruments, 1092), the Daming Hall lantern clock and Emperor Shunji’s elaborate clock with jacks (figurines) to announce the time automatically as described in the *Yuan Shi* (元史, History of the Yuan [Dynasty], 1369–1370), and various books from the Sino-Islamic tradition of striking clepsydras. Toward the end of the Goryeo dynasty and throughout the Joseon dynasty (1392–1910) astronomical, calendrical, meteorological, and clepsydral affairs were entrusted to the royal observatory known first as the Seoungwan (書雲觀) and then the Gwansanggam (觀象▯). King Taejo (r. 1392–1398), the founder of the Joseon dynasty, built in central Seoul a Bell Tower (鐘樓, *Jongnu*) which announced the time provided by a newly cast

Time in Korea. Fig. 1 King Seongdeok’s God Bell at Bongdeok Temple, cast in 771. It announced dawn and dusk in Gyeongju, the capital city of the unified Kingdom of Silla (Korean National Treasure Number 29, restored at the National Museum in Gyeongju).

night-watch[1] clepsydra (更漏, *gyeongnu*) in 1398. The third Joseon king, Taejong (r. 1400–1418), was a scientifically inclined ruler who worked with his son, the future King Sejong (r. 1418–1450), to improve printing Palace Guard technology and clock-making. Assisting them was the Chief Court Engineer Jang Yeong-Shil who cast a new night-watch clepsydra (更點之▯, *gyeongjeomgi*, instrument with night-watches and [their] points) in 1424. Sejong became particularly interested in astronomy and, in 1432, initiated a project to reequip the royal observatory Ganeuidae (簡儀臺) using calendrical corrections in the *Shoushili* and the *Datongli* (大統曆, Calendar of the Great System) from Ming China. While the project was underway, 15 kinds of astronomical instruments and clocks were made, including two monumental water clocks by Jang and four kinds of sundials (see “Astronomical Instruments in Korea”). How the clocks were made is recorded in the *Sejong*

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[1] “Night-watch” and “night-watch point” are technical terms from ancient Chinese timekeeping. The expression “night-watch” is used for the Korean word *gyeong* (更, *geng* in Chinese), about a 2-h period in the nighttime. There were five *gyeong* each night, corresponding with the 2-h blocks or “double-hours” from around 6 p.m. to 6 a.m., and each *gyeong* was divided into five *jeom* (點, *dian* in Chinese), an expression translated as (night-watch) “point.”

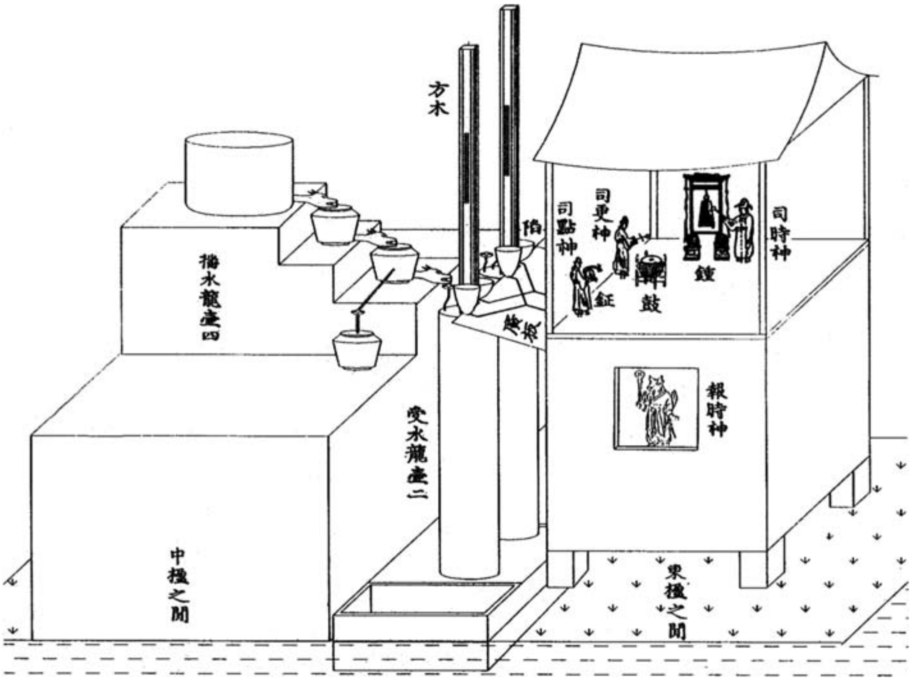
Sillok (世宗實錄, Factual Record of Sejong), which is supplemented in the *Cheungbo Munheon Bigo* (□□□□□□, Enlarged [Edition of] Documents and Notes, 1903–1908), a comprehensive study of civilization.

After the Japanese invasion of Korea late in the sixteenth century and during the emergence of the Qing dynasty in China during the middle of the seventeenth century, a Western-style calendrical system called the *Shixianli* (時憲曆, Calendar of the Constitution of Time) was adopted and several mechanical clocks were introduced through China and Japan in the 1630s and 1660s. In 1669 the horologist Lee Min-Chul and the Professor of Astronomy Song I-Yeong respectively made a traditional water-operated clock and a Western-style armillary clock driven by weights.

The *Jagyeongnu* (Self-Striking Water Clock)

The *Jagyeongnu* (自擊漏) is an elaborate timekeeper which announced the 12 "double-hours" (2-h blocks) that corresponded to the animals of the Chinese zodiac – the rat (which straddled midnight), ox, tiger, rabbit, dragon, snake, horse, sheep, monkey, rooster, dog, and pig – as well as the five night-watches (*gyeong*) that covered the hours from around 6 p.m. to 6 a.m. (and corresponded with the rooster, dog, pig, rat, ox, rabbit, and tiger) and their five "points" (*jeom*). Details about the *Jagyeongnu* are recorded in the *Sejong Sillok*, under the first day of the 7 month of the 16th year of Sejong's reign (1434), in the memoir *Borugakki* (報漏閣記, Description of the Announcement of the Clepsydra Pavilion) that was written by the court official Kim Don. Having been completed in 1434 under the commission of Sejong, it was an improvement on the clepsydra of 1424 and is divided into three parts (Fig. 2).

The inflow part of the clepsydra has four water-supplying vessels and two measuring vessels for everyday changeover. A floating indicator rod, graduated for the 12 double-hours and the points of the five night-watches, was in the measuring vessels, while above these vessels were wooden vertical ball racks with 12 (for the double-hours) and 25 (for the five points of the five night-watches) small bronze balls. The rod would rise and release horizontal latches that let the bronze balls out; the balls then fell and ran along an inclined channel to cause a set of 12 and 25 iron balls about as big as a hen's egg to trigger the time-announcing mechanisms. These mechanisms consisted of two ball-relays and an audible time signal for the double-hours and the night-watches, a visible time-indicator for the double-hours, three wooden jacks which sounded a bell for the double-hours, a drum for



Time in Korea. Fig. 2 The *Jagyeongnu*, "Self-Striking Water Clock." *Left*: The inflow part of the clepsydra consists of a reservoir, compensator, regulator, and overflow receptacle; two measuring vessels are on the floor bed. *Middle*: Two ball racks are implanted on the measuring vessels, which release small bronze balls through the holes that correspond to the 12 double-hours and the five night-watches. *Right*: Devices to announce the time are in the box, and the three jacks on the box strike a bell, drum, or gong; the jack in the middle of the box displays the time by showing the double-hour through the window as the bell is stricken.

the night-watches, and a gong for the night-watch points.

The ball-relaying mechanisms were separated by two large channels for the balls to move along. One channel allowed the balls to cause a jack in the form of a god to ring its bell for the double-hours; it also caused a horizontal wheel with 12 small gods to turn so that the appropriate god would display its double-hour tablet, an example having the character 午 for the hours of the horse (11 a.m. to 1 p.m.). The second channel caused another jack in the form of a god to announce the night-watches by striking a drum the appropriate number of times (e.g., three for the third night-watch), while a third god sounded a gong once for the beginning of a night-watch as well as the appropriate number for each night-watch point (e.g., five strikes of the gong for a fifth *jeom*).

During the Japanese invasion of Korea in 1592, this clepsydra was destroyed, but details about how this ingenious combination of balls and levers operated the mechanisms for announcing time are in the above-mentioned literature and in Joseph Needham's monograph *The Hall of Heavenly Records* (1986: 27–30). Figure 3 is a reconstruction of the *Jagyeongnu* made by the present author and his associates at the National Palace Museum of Korea, and details are in the author's monograph *Jang Yeong-Shil and Jagyeongnu*: *Reconstruction of Time Measuring History of Choseon Period* (2002).

In 1536, by order of King Jungjong (r. 1506–1544), the horologist Park Se-Ryong made a new striking clepsydra for the Changgyeong Palace in Seoul. Similar to the water clock made at the time of King Sejong, the new clepsydra had however an independent time calibrator. Although it had broken down at the time of the Japanese invasion, parts of it that included the major vessels for supplying water survived and were restored, and under King Gwanghae the time-announcing mechanisms were back to work in 1608 in the rebuilt clock house near the former place. After the Jesuit-designed *Shixianli* was adopted late in the seventeenth century, the clock operated on a system of 12 double-hours and 96 intervals; this new system also replaced that of the 12 double-hours and 100 intervals (each interval corresponding to 14 min, 24 s), both of which comprised one full day according to the *Datongli*, with the 24 h and 15-m quarter hours of the Western tradition. The clepsydra operated automatic sounding devices to announce the time, but this came to be done by manually striking a bell, drum, and gong after the building with the clock fell into disrepair in the early nineteenth century. Until the end of the traditional curfew system late in the nineteenth century, this clepsydra had operated as a timekeeper for roughly 350 years. In 1938, what remained of it was moved to the Deoksu Palace in Seoul, and in 1985 the parts were collectively entered as "National Treasure Number 229" (Fig. 4).

The *Heumgyeonggaknu* (Water Clock with the Pavilion of Prudence and Respect)

In 1438, Jang Yeong-Shil made the *Heumgyeonggaknu* (欽敬閣漏), another striking clepsydra. Besides announcing hours automatically by mechanisms known as jade-clepsydra mechanical wheels that were rotated by trickling water, it also displayed celestial movements. The armillary part of this machine had a golden

Time in Korea. Fig. 3 The *Jagyeongnu* made by the present author (NAM M-H) and his associates in 2005 restored at the National Palace Museum of Korea.

Time in Korea. Fig. 4 Relics of the self-striking clepsydra made in 1536 after that commissioned under King Sejong in the 1430s (Fig. 2). Shown here, from the *upper left*, are the reservoir for supplying water, compensator, and regulator vessels, and the two measuring vessels on the floor bed stand two meters high. The parts which announced time have been dismantled. (Korean National Treasure Number 229, the *Jagyeongnu* of the *Borugak*, preserved at the Deoksu Palace since 1938).

model of the sun which moved daily along the peaks of a mountain that was surrounded by five-colored clouds. The clepsydra part had three mechanisms for announcing time: (1) a set of four female jacks in the form of goddesses standing at the four cardinal directions on the mountain peaks and holding wooden mallets to strike at the double-hours, (2) similar to the clepsydra in the previous section, a bell was struck by a jack at the beginning and middle of the double-hours, a drum for the night-watches, and a gong for the night-watch points; and (3) at the base of the mountain, 12 gods represented the animals for the double-hours (rat, ox, tiger, etc.), and each would descend into a hole during its time period as a jack came out of a slot with a tablet bearing the double-hour time. Besides these mechanisms for announcing time, an inclined vessel on another platform automatically was filled by and emptied water which overflowed from the clepsydra. Because the mountain was surrounded by rural scenes from the four seasons and wooden carvings of men, birds, and plants that express labor and difficulties in agriculture, this timekeeper emphasizes the importance of measuring time and making calendars in Neo-Confucian ideology. Ideas from traditional Chinese armillary clocks, such as that of Su Sung in the *Xinyixiangfayao*, and Arabian water clocks were combined to make this automatic armillary clock, which Korean kings had reproduced several times as a symbol of the political ideology of the state. Fig. 5 is an artist's rendition of what this interesting clock looked like.

The *Honcheoneui* (Instrument About the Entire Heavens) and *Jamyeongjong* (Self-Ringing Bell)

In 1669 King Hyeonjong ordered the jade clepsydra system of the *Heumgyeonggaknu* from the time of King Sejong to be rebuilt, and this led to two new armillary clocks being made. One was a relatively traditional water-operated instrument by Lee Min-Chul, which had driving and time-announcing mechanisms like those in the striking clepsydra, jade clepsydra, and King Sejong's armillary sphere from the 1430s. It was a late survivor of the ancient Sino-Korean tradition of water-operated clocks that represented the universe and were operated in completely traditional ways (Needham et al. 1986: 110). Except for not having a compact weight drive, Lee's armillary clock was quite similar to the other made at this time.

Based on a Chinese clock which had been presented to King Injo in the 1630s by a Western missionary stationed in Beijing, Song I-Yeong produced a Western-style, weight-driven apparatus called the *Honcheoneui* (渾天儀) and a self-sounding clock known as, after the Chinese name, the *Jamyeongjong* (自鳴鐘). Song's clock combined Sino-Arabian wheels with jacks, a traditional armillary sphere that represented a rotating-earth system, and a weight-driven clockwork mechanism that had reached Korea via Japan. While making repairs in 1687, Lee Jin replaced a telescopic mechanism with a terrestrial globe and a clockwork mechanism, which was converted into state-of-the-art technology that Christian Huygens had developed in 1672 in Paris. Although it is not known for sure, Huygens' clock probably had been imported from Japan during the reign of King Sukjong (1674–1720). Lee's clock came to be known in the West through studies by Carl Rufus in the 1930s, and in the 1970s Joseph Needham and others did a detailed study on Lee's clock and armillary sphere (Needham et al. 1986: 115–152). From the eighteenth century onwards, royal clock-makers in Korea made weight drives of the sort used by Song in his clock, and parts of Song's clock itself have survived (Fig. 6). They were donated by Kim Seong-Su (a former Vice President of the Republic of Korea) in the 1950s to the Korea University Museum, where they have been restored and, in 1985, became "National Treasure Number 230."

Time in Korea. Fig. 5 Artist's impression of the *Heumgyeonggaknu*, showing the model of the golden sun revolving around the mountain. Standing on the multicolored cloud and facing each of the cardinal directions are four jade girls who strike golden bells with wooden mallets to announce the double-hours; as they do this, the four tutelary spirits (Black Warrior, Blue Dragon, Red Bird, and White Tiger) also face in their respective cardinal directions. At the southern foot of the mountain a jack and three warriors strike the double-hours, night-watches, and night-watch points with their instruments in a similar fashion as that for the *Jagyeongnu* (Fig. 3). At ground level are the 12 animals of the Chinese zodiac which correspond to the double-hours. At midnight (11 p.m. to 1 a.m.), for example, the hole behind the Rat opens, an hour god with a tablet announcing the time comes out, and the Rat stands still. South of the mountain, a man with a vase pours water into an inclined vessel which lies on its side when empty, stands upright when half full with water, and falls over when it has been completely filled. The rural scenery, from the four seasons, depicts various types of labor performed around the mountain by peasants. The design for this impression was made by Prof. Hahn Young-Ho, the author of "Astronomical Instruments in Korea."

Time in Korea. Fig. 6 What remains of Song I-Yeong's armillary clock. At the left is the armillary sphere, in the center a striking train and weights to strike the clock and bell, and at the right a time-announcer, gong train, and striking-release mechanism. The measurements are 120 (length) × 98 (height) × 52 (breadth) cm; courtesy of the Korea University Museum.

See also: ▶Time in China, ▶Astronomical Instruments in Korea

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Time in Maya Culture

Henry J. Rutz

Classic Maya culture developed from the second to the tenth centuries AD and expanded to encompass all of the Yucatan peninsula including the modern countries of Guatemala, Belize, and portions of El Salvador and Honduras. Unlike the Aztec and Inca states, which developed highly centralized imperial cities, the Maya developed city-states. Elites intermarried, formed alliances, and shared a complex calendar.

While all empires have created multiple times to connect village community to imperial center, and earthly city to heavenly city, the historian Nancy Farriss has noted that "from their earliest recorded history, the Maya displayed an intense interest, bordering on obsession, in measuring and recording the passage of time." Anthony Aveni (1989) observes, "The first bits of information in any Maya inscription are about time. What sets the Maya apart is not the number of time units they devised, or even their complexity; rather, it is their preoccupation with 'commensurateness' – perfecting the way time cycles interlock or fit together." Over a millennium since the climax of classic Maya culture and five centuries after the Spanish conquest, Maya continue to practice their own time, albeit in modified form.

The Maya had a military state with a literate elite. Our information about their multiplicity of time comes from their own writings. Although Maya hieroglyphic writing died out, Maya elites were able to maintain an unbroken continuity from their system of writing to that of Spanish script. The language survived in many colonial documents from the sixteenth century on. Today two million people still speak more than a dozen dialects of the Mayan language.

The Maya calendar is the centerpiece of Maya concepts of time and its measurement. It consists of the conjunction of cycles upon cycles of time of long duration. Like the Gregorian calendar we use today, the Maya calendrical system was the culmination of many different cultural influences over millennia. The conception of time underlying the calendar is one of movement. Maya referred to time as a flow and perceived a need for both human and divine intervention in maintaining it. In Maya culture, people actively construct their sense of time, a point to which I return below with reference to daykeepers and their role in the regulation of everyday life.

The flow of time is incorporated into an all-encompassing cyclical pattern. Conjunction of complex forces mark cycles of different duration. The Body Count of twenty is the basic unit of Mesoamerican counting (ten fingers plus ten toes). The classic Maya week consists of twenty named days, each propitious or unpropitious for particular activities. The twenty-day week was combined with a separate series of thirteen numbered days to create the Sacred Round of 260 days. Later, a Solar Year was calculated consisting of eighteen twenty-day months plus five days. The solar year was articulated with the sacred round to create the Calendar Round of 52 years. The Maya also developed a Katun Round consisting of thirteen twenty-year periods for a duration of 260 years. Despite an obsession with commensurability that led Maya priests into astronomy and cosmology, not all the cycles were articulated with each other. Late in the political development of pre-Conquest Maya culture a Long Count of five millennia appeared. Today, Maya daykeepers reckon the rhythms of everyday life by interpreting the solar and divinatory calendars.

Although Maya viewed time as a flow, it is also time with a content. Each day was named after a god and was qualitatively different from every other. Furthermore, the content of time was regulated by a conjunction of forces. Those days that were at the conjunction of different cycles had a greater force than other days. The larger the cycle, the greater the number of forces intermeshing from different subcycles. The Maya depicted time on stone carvings or drawings as weighty numbers carried by gods.

Intermeshing cycles produce a succession of days whose events are linear, unique, and irreversible. But this apparent linearity is an illusion because “no matter how unique a pattern of events may seem, no matter how long the sequence, it will eventually be repeated, when the governing forces of all the cycles of different dimensions coincide in one huge cycle” (Farriss 1987).

Why these cycles? Maya observers were not disinterested observers of the heavens. Cosmic time links common people to rulers through the latters’ association with the cosmos. The construction of cycles appears to be associated with the problems of legitimacy and political order. Returning to the same point, at least logically, is the ultimate form of reassurance against the reality of present conflict, chaos, and events that seem to be getting out of hand. As Farris says, “Accounts of the famine in the books of Chilam Balam show less concern with starvation than with the fact that people flee into the forest to eat roots and other wild food… In other words, people cease to live in their customary fashion... Political conflicts are condemned because they disrupt the established hierarchy, and upstarts and invaders are vilified for breaking the rules.” Encompassing cycles provide a cosmic charter of legitimacy of a magnitude rarely conceived in the history of cultures.

The predictable order of cosmic time reckoning, unfortunately, depended upon human agency for execution. “It is unlikely that the Maya priests claimed to comprehend all the possible combinations of divine forces governing the subordinate movements of so immense a projection.” Past, present, and future are written in a single bound book, but one that admits of many interpretations.

How did the dual conception of cyclical and linear time work out in practice? Both serve as charters for sociopolitical arrangements, but each in its own way. It appears that classic Maya elites confined linear concepts to relatively short term duration out of choice (they possessed the literary or numeracy skills to create historical memory). Among the most important were the katun round and the chronicles written by members of Maya royal lineages during the colonial period.

The katun round, consisting of a recurring wheel (time is often depicted as a wheel in Maya stone carvings) of thirteen twenty-year counts for a total of 260 years, recorded the important events of royal lineages. The interesting aspect of the katun round is its duality of both history and prophecy. Each year has its own name together with characteristic and appropriate events. The future is contained in the past, and therefore Maya could look to a record of the past as a guide to the future. The same pattern of events for a given year recurs every 260 years. In Chilam Balam texts, logically associated events always occur in the same katun regardless of their inner chronology. It is as if all invasions were taken out of their chronological sequence and placed in their cosmological reckoning. Even references to the most recent “descent” – the Spanish conquest – are woven into the pre-Hispanic mix.

In addition to general reference to recurrent patterns of events there is also remarkable specificity to katun accounts, which name specific people and places, details of real famines, invasions, migrations, exiles, and rivalries. The specific content is about unique and irreversible events. The chronicles appeal to secular principles as the basis for claims to legitimacy, for example descent from previous rulers. The twenty-year katun cycle may have served as a calendar for rotation and succession of ruling families in post-Classic Maya. In contrast, books of Chilam Balam that record cycles stress quality of time – joy, misery, abundance, and the place of cosmic and divine forces in their production. The sacred personages of the calendar rounds merge with their worldly actors.

There is some evidence that the Maya calendar evolved toward a dominance of linear over cyclical concepts of time during the post-Classic period as a consequence of the emergence of dynastic rule and its dominance over the more autonomous city-states of the Classic period. Unlike the calendrical system of cycles and their conjunction, which have no particular starting date, the Long Count system measured elapsed time from a starting point that would extend to a time horizon of 5,200 years before its repetition. This new calendar represented a radical shift from the dominance of cyclical time over linear time because its duration was long enough to encompass the ancient Calendar Round of 52 years and more recent katun round of 260 years. Specific details of human affairs accompany the Long Count and a new emphasis on written genealogies supports the hypothesis of a shift to dynastic rule.

If it is unlikely that ancient Maya priests could comprehend all the divine forces converging on particular days or years, how much less likely is it that ordinary people could use the Maya calendar to take control of their own lives? A partial answer appears in the guise of Maya daykeepers. Barbara Tedlock (1982) has given us an account of time among Quiche Maya in the town of Momostenango, highland Guatemala. There daykeepers use an integrated solar year and the sacred round to divine whether a day is good or bad for particular activities. The appropriate determination of qualities to a day are specific to a particular client and require active participation on the part of both daykeeper and client.

Daykeepers use a set of practices referred to as “the speaking of the day” and “the speaking of the blood.” The qualities of the twenty name days are based on stipulated but vague mnemonic phrases that require interpretation by the daykeeper. Other factors specific to a client enter the picture, including the client’s character, part of which is determined by the particular day on which a child is born.

The daykeeper achieves understanding by sortilege or divination by lots. She or he mixes, grabs, and arranges piles of seeds and crystals into a pattern, all the while counting and interpreting the 260 days of the divinatory calendar. The blood is considered to be an active substance that sends signals or “speaks” to the daykeeper. The rapport between daykeeper and client is also thought to affect the divining of a day as good or bad for a particular activity. Clients come to a chosen daykeeper with a specific question about such probable occurrences as illness, accident, land disputes, building houses, inheritance, business transactions, travel, marriage, adultery, quarrels, dreams, births, deaths, and interpretation of omens. The divination is performed for the specific question posed by a particular client.

See also: ►Calendars, ►Long Count, ►Writing, ►Mathematics

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Time in Native North America

Michael Zeilik

The Pueblo people of the United States Southwest believe in a cosmos in which nature functions with the active cooperation of humankind. The proper ceremonies must be carried out at the proper time so that the cosmic order is sustained. Traditional doctrines held that there were correct times for planting, harvesting, hunting, ceremonies, and many other activities – all embedded in a sense of sacred time. The right times for these crucial undertakings are established by astronomical observations to regulate the ritual calendar. The cycles of the sun and moon set the rhythm of Pueblo time.

Sacred time is ordered with different levels of periodicities. The longest appears to be the seasonal year. We have very little evidence – almost all ambiguous – that the Pueblos kept long counts or tallies greater than a year. Until the twentieth century, with the intrusion of European concepts of time, no indigenous interest appears in tracking cycles over many years. The yearly cycle is all important; after its end, a new, equally unique one begins. Within the seasonal span, ceremonies occur in a fixed sequence, in which the completion of one sets the stage for the next. The observation of the phases of the moon marked the subdivision of the year. Within a night, the start and end of some ceremonies are flagged by observations of the positions of certain stars, especially the Pleiades as seen from the smokehole of a *kiva*, a structure used as a ceremonial room.

The shortest unit of time reckoned by the Pueblos is the day, which begins with sunrise. The day has vague subdivisions into loose “hours,” most of which are noted near sunrise and sunset by the color of the sky. About the only time of day noticed with any care is that of noon, which is typically observed by the length and directions of shadows cast by the edges of walls, buildings, trees, or sticks embedded in the ground.

A religious official has the responsibility and the authority to set the ceremonial dates within the ritual cycle. The crucial task entrusted to this official is the forecasting of the correct date by making anticipatory astronomical observations. The dates are announced ahead of time so that the people of the pueblo can enter into proper preparations (abstinence, practicing songs and dances, preparing costumes and special foods) so that the ceremony may be carried out with “good heart” and be effective.

Typically, one official – the Sun Priest – performs the sun-watching for the seasonal cycle, which includes the planting schedule. He does so from a sun-watching station that is usually located within or close to the pueblo. From this fixed spot, the Sun Priest keeps a horizon calendar (usually at sunrise using an observation of the first gleam) against the horizon profile. He knows from experience that when the sun rises (or sets) against a certain horizon feature, so many days will elapse until, say, the winter solstice. Then he uses tally markers (such as a knotted cord) to count down to that day, with an announcement made to the pueblo a few days ahead of the celebratory date. This anticipatory technique allows the Sun Priests to forecast the dates of the solstices to within 1 day of the astronomically correct date when the sun appears to "stand still" at its sunrise point. The observations made about two weeks in advance catch the sun when the angular speed of its sunrise position is large enough to be discerned by the naked eye on a day-to-day basis. Hence, this practice neatly solves both a cultural and astronomical problem.

Moon watching regulates timings between the seasonal and daily ones. The official responsible for tracking the phases of the moon generally is not the one who watches the sun. A Pueblo month begins with the observation of the first visible crescent and ends with the last. The days of invisibility are not typically counted. Calendar sticks were used to tally the observed months.

The months of the year are counted starting with the first before the winter solstice ceremony. The first five (or six) are named (usually after seasonal characteristics); then these names are repeated for the next five or six. The lunar calendar needs to be synchronized with the solar one, which is accomplished by adding an intercalary month (which can be as short as four days!) at the end of the regular count or after the winter solstice.

Although Pueblo people feared eclipses of the sun and the moon, they had no way to forecast them. In part, this lack was related to their disinterest in keeping counts longer than a year. We also find no evidence for knowledge of the 18.6-year lunar standstill cycle, even though the moon certainly was observed rising and setting. The historic Pueblo culture did not seem to attach any importance to this astronomical cycle so it was ignored.

The ancestors of the Pueblo people were the Anasazi, who inhabited what is now the greater Four Corners area of the US Southwest as a settled agricultural people. During the height of the classic Anasazi culture some thousand years ago, two major sites developed: Mesa Verde and Chaco Canyon. A regional center developed in the San Juan basin around Chaco by AD 1110; as many as 70 communities dispersed among 50,000 km^2 were integrated into a socioeconomic and ritual network connected by a road system.

How did the Anasazi regulate and track time? By using ethnographic analogy, we can generate hypotheses about Anasazi astronomy that can be checked against the archaeological record. The most important cycle of time for the Pueblos is the seasonal year, which is typically tracked by horizon calendars. Anticipatory observations are made about two weeks prior to the solstices. Of the Anasazi sites field-tested so far, about one-third have reasonable horizon calendars.

A secondary strategy employed in the historic Pueblos used a special opening or window to cast sunlight on an opposing wall. The best Anasazi analogs to this type of interior observational technique occur in Hovenweep National Monument at Hovenweep Castle, Unit Type House, and the Cajon Group ruins with small portals. Hovenweep Castle and Cajon ruins work at sunset, Unit Type House just after sunrise. In all three locations, the horizon profiles lack the relief for tracking horizon calendars. For all, the throw from the shadow-casting edges is large enough so that the linear motion on the receiving wall is typically a few centimeters per day from the sun's angular positional change at sunrise or sunset. The evidence so far hints that interior light and shadow casting played an important role in Anasazi seasonal time keeping.

Exterior light and shadow casting was not an important time keeping technique in historic times. It may have been used more extensively by the Anasazi though perhaps more for ritual than calendric purposes. The three-slab site atop Fajada Butte in Chaco Canyon has been much investigated; so has the Holly site at Hovenweep. In both these cases, light and shadow cast by rock edges fall onto panels of rock art at important seasonal times of the year. These exterior sites generally suffer from a lack of resolving power for reliable calendric forecasting, if we apply the standard achieved by the historic Pueblo Sun Priests – within a day of the astronomical date of the solstices. Hence, these sites may have served as sun shrines for offerings to the sun with a light and shadow display that served a commemorative rather than a calendric function.

We have no firm evidence so far of prehistoric monthly lunar calendars, though such a count of days would have a unique sequence tied to the phases of the moon. No rock art in the Anasazi region has been demonstrated to display the measure of a lunar tally.

Occasional claims have been made that the Anasazi noted the 18.6-year standstill cycle of the moon. The hypothesis of attention to this interval has been put forth for the Fajada three-slab site and for Chimney Rock Archaeological Area in Colorado (among a few others). The most convincing case is made for Chimney Rock, where the natural rock pillars (after which the site is named) act as a natural foresight when viewed from the site of Chimney Rock Pueblo, a Chacoan outlier, which was occupied from about 1075 to 1175.

The orientation allows a spectacular anticipation and forecasting of the major lunar standstills. For about two and a half years prior to the standstill, the moon rises between the pillars for 1 or 2 days per month. Starting after the summer solstice, the moon appears as a waxing crescent. Finally, near the winter solstice, the full moon stands between the pillars at around sunset. Hence, the priest in charge of the moon watching could forecast the date of the standstill and also the full moon nearest the winter solstice – an important conjunction among the historic Pueblos.

See also: ►Long Count, ►Astronomy

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Time: Non-Western Views

C. K. Raju

Time is a difficult notion, since time beliefs underlie a variety of seemingly unrelated areas like (1) scientific theory, (2) philosophy of science, (3) religious beliefs about the nature of life after death, and consequently about the soul (4) human values and the (5) nature of language and logic, etc. These various time beliefs may or may not cohere with each other.

The structure of the English language, unlike that of the Hopi (American Indian) language, presupposes that time and space are entirely separate entities, and this makes it hard to understand the intermingling of time and space in relativity theory. As another example, the Buddhist Dhamma (ethics, way of life) is closely connected to the Buddha's concept of *paticca samuppāda*, or conditioned coorigination, the proper understanding of which requires the concept of a structured time, in which the instants of time are not featureless geometrical points. This notion of a structured time is incompatible with the two-valued logic assumed in Western philosophical discourse. In Buddhist thought, seemingly contradictory properties may coexist, as in the quantum-mechanical Schrödinger's cat who is both alive and dead at a single instant of time. Thus, the attempt to understand one aspect of a non-Western view of time, such as the Buddhist notion of *paticca samuppāda*, can force us to reconsider fundamental issues like the logic underlying Western thought.

Any attempt to provide an account of non-Western views of time is a very difficult enterprise, involving complex relationships across widely different areas of knowledge, and potential conflicts at a deep level with stock metaphysical assumptions underlying even the language and logic of Western discourse. This entire gamut of relationships between different pictures of time has been covered in the books *Time: Towards a Consistent Theory*, and *The Eleven Pictures of Time*, by this author, but it is too complex to be covered in the span of this one article, which will focus on only a single aspect related to the Western stereotype of non-Western beliefs about time.

The Western stereotype: "linear" time versus "cyclic" time

Non-Western views of time have typically been represented in Western literature and scholarship by contrasting Western "linear" time with non-Western "cyclic" time. Linear time is endowed with a variety of positive properties: rationality, progress, free will, etc. while cyclic time is attached to a variety of negative properties: spirituality, stasis, fatalism.

The first step needed to understand non-Western views of time is to get rid of this stereotype.

For example, the time beliefs underlying scientific theory are not the same as those underlying the philosophy of science, and the two do not cohere, but both can be classified as linear time. Thus, scientific theory is today presented in the form of differential equations, such as Newton's laws of motion, or the Hilbert-Einstein equations, or Schrödinger's equation. These equations fix the state of the cosmos at any time, once its initial state is known. However, all these equations involve the mathematical notion of a derivative with respect to time – for example, velocity, or the rate of change of position, is the time derivative of position, and acceleration is the rate of change of velocity or the time derivative of velocity. On the existing Western mathematical understanding of the calculus, these derivatives with respect to time force us to suppose that time is a continuum, which can be represented using real numbers. That is, current scientific theory necessarily presupposes that time is like the real line, or that time is "superlinear".

On the other hand, our reasons for believing in this or that scientific theory are (or ought to be) based on experiments, and this presupposes the belief that one can perform various experiments, the outcomes of which were not all determined beforehand, by the state of the cosmos at some moment in the remote past. That is, the philosophy of science presupposes a different belief about time: that the future of the cosmos is a consequence of human choices and actions, and not merely of its past state. One does not normally stop to think about such presuppositions because everyday human actions are premised on the same belief that human actions are powerless to change the past ("no use crying over spilt milk") but that they do bring about the future in some small way ("if I don't watch the milk it will boil over"). Thus, the philosophy of science subscribes to the belief in "mundane time".

These two types of time, superlinear and mundane, are both linear, but they are nevertheless incompatible and in conflict with each other. This conflict is a serious matter, for it pits scientific theory against the reasons for regarding it as valid. How is this conflict to be resolved? This would naturally seem to require a correction in one or the other picture of time.

However, the slightest alteration in one's time beliefs can have profound consequences. Changing the picture of time in scientific theory fundamentally changes the type of equations used to formulate the models of physics. On the other hand, if one were to believe that the future of the cosmos has already been rigidly determined by its past, there would be little point to human action, and life itself would become meaningless, as in the theory of the Stoics, or in Nietzsche's thought.

Since there are different notions of linear time, such as superlinear time and mundane time, which do not cohere with each other, so the very category of linear time is not meaningful. The category of cyclic time is not meaningful for similar reasons.

On the other hand, there need not be any particular conflict between a locally superlinear time and a globally recurrent cosmos. If the cosmos is restricted to a finite region, like a gas in a box, and evolves deterministically – according to Newtonian mechanics, say – then the Poincaré recurrence theorem tells us that, with probability one every state of the cosmos must repeat to an arbitrary degree of precision, infinitely often. Recurrence would similarly take place even if the cosmos evolves probabilistically rather than deterministically, so long as the future state of the cosmos depends only on its present state, an assumption more precisely formulated in current mathematics as the Markovian assumption for the evolution of a stochastic process. These recurrence theorems assure us that a recurrent cosmos, instead of being in conflict with superlinear time, is a logical consequence of it, under some rather general conditions, such as finiteness. In the above situations of cosmic recurrence, it could be argued that time only seems superlinear because the time scale of cyclicity – the recurrence time – may be very large, just as the earth seems flat, although it is round, since it is very large. Thus, a linear picture of time, need not be in conflict with a cyclic picture of time.

This meaningless dichotomy of linear versus cyclic time has nevertheless been persistently used in the West to characterize non-Western thought about time. A non-Western historical perspective on the development of Western time beliefs is helpful in understanding the origins of this incorrect (but widespread) stereotype about time and its linkage to religious ideology.

Quasi-Cyclic Time and the Soul

Early notions of the soul (in India, for example) were based on the belief that the cosmos went through recurrent cycles, or, equivalently, that time was quasi-cyclic. It was believed that each cycle of the cosmos lasted for an enormous duration of time – billions of years – and that each cycle of the cosmos was approximately like the preceding one. Events repeated in approximately similar ways in successive cycles of the cosmos. Roughly the same people were reborn in successive cycles of the cosmos, and lived roughly the same lives, and died roughly the same death repeatedly, across cosmic cycles. This perceived state of affairs was described by saying that each individual has a soul, which persisted beyond death, and was repeatedly reborn (in successive cycles of the cosmos), until such time as it achieved deliverance.

The duration of a cycle of the cosmos is reckoned in the *Viṣṇu Purāṇa* as a day and night of Brahma, and amounted to 8.64 billion years. (An ordinary day and night amount to 86400 seconds.)

This notion of a soul which persists across vast cosmic cycles is not a metaphysical notion, since it presupposes a cosmic state of affairs, which may or may not be the case. That is, this notion of the soul is a physical notion, since it involves a refutable or falsifiable picture of the cosmos.

It is a common error to confound quasi-cyclic time with eternal recurrence. It was not generally believed that these cosmic cycles were exact or eternal. The whole possibility of deliverance – *mokṣa*, *nirvāṇa* – was premised on the idea that these cycles were neither exact nor eternal. (However, the category of cyclic time encourages such an error by suggesting that various types of cyclic time are the same.)

In India, this was the traditional view of time and life after death held from before the time of the Buddha. The Lokāyata denied the belief in life after death as a fraud. An interesting feature of this denial is how Pāyāsi sought to establish the non-existence of the soul by performing some 37 experiments with dying men, and condemned felons. It is unlikely that such experiments were ever performed anywhere else.

The Buddhists did not deny this cosmic state of affairs. Indeed, popular stories like the *Jātaka* tales clearly accepted what was then the prevalent common belief about the world. What Buddhists denied was only the significance of cosmic recurrence, for they denied the existence of a soul or any continuity between two similar individuals across two cycles of the cosmos. In fact, they also denied that anything essential persisted between two similar individuals across even two instants of time: they maintained that the seed in the granary is a distinct entity from the seed in the ground, which is bloated. The seed in the granary cannot be the cause of a plant, because the seed in the granary remains a seed at the next instant. There is a similarity between the two seeds, and hence, due to the paucity of names, one gives the same name to both seeds. Therefore, in the Buddhist view it would not be proper to say that there is some essential sameness in an individual which persists from birth to death: in the Buddhist view, an individual exists (unchanged) only for a single instant.

This notion of quasi-cyclic time is incorporated in artistic or mythical representations, like the Wheel of Time, the Phoenix, or the Plumed Serpent of Central America, that are found from across the world, and certainly existed in Egypt. And, as Herodotus informs us, numerous ideas, customs, and religious beliefs were transmitted from the Egyptians to the early Greeks. Therefore, it is not surprising that a similar notion of the soul is found in the works of Plato, and was subsequently developed by the Alexandrian Neoplatonic philosophers.

Indeed, it is little known that this belief in quasi-cyclic time was the anchor of early Christianity, as enunciated by one of its greatest real (as opposed to mythical) teachers, Origen of Alexandria (3rd–4th century CE). This early Christian notion of cyclic time was remarkably similar to what is today known as the Hindu doctrine of *karma-samskāra*. According to this doctrine, the actions (*karma*) in one cycle determine the dispositions (*samskāra*) in the next cycle, and the objective of life is taken to be deliverance (*mokṣa*) from these repeated births and deaths.

Quasi-Cyclic Time, Immanence and Equity

Curiously, while cyclic time and *karma-samskāra* are today associated with casteism and inequity, in early Christianity, Origen argued in his *De Principis* that this notion demonstrated both equity and justice: equity, since God had created all souls equal, and justice, since souls were rewarded and punished in each cycle of the cosmos according to the merits or demerits they had earned from their good or bad actions in the preceding cycle. Origen's argument was not an isolated curiosity.

Thus, the notion of equity was related to immanence or the idea of divinity with in man, and hence the importance of deep introspection. The discipline of Yoga (union) is not a physical exercise, but a technique of meditation or introspection to bring about the union of ātman with Brahman, inside man, and thence lead to deliverance. Mathematics (geometry) was perceived by early Greeks to be a technique, exactly like Yoga, to achieve the same goal. Thus, in Plato's *Meno*, Socrates demonstrated the slave boy's prior knowledge of mathematics, in support of his theory that all learning was but reminiscence of the prior knowledge of the soul. Likewise, Proclus explained the etymology of mathematics (from *mathesiz* or learning) as the science of learning, or the science of the soul, since he thought mathematics related to eternal truths, and forced one into an introspective state, which then aroused the immortal soul and induced it to recollect its past knowledge, which it had forgotten since birth.

Immanence related to equity, since all souls were regarded as being part of one God. This relation is well brought out by the following story. Śankara was the founder of Advaita Vedanta, a philosophical system which asserts that ātman and Brahman are "not two" (but one). Śankara was returning from his bath in the river, when he was accosted by a *candāla* (outcaste). By force of habit, Sankara shrank back. After this the *candāla* taunted him, asking how Śankara could maintain this distinction when both had an ātman one with Brahman, hence equal to each other. Realizing his mistake, Śankara prostrated himself before the *candāla*. Almost every theorem of Euclid's *Elements* is about equality (not congruence), and this was unambiguously related to political equality as in the mystery story that there is "no royal road to geometry". The connection to political equality was made quite explicit in subsequent Islamic rational theology (*aql-i-kalam*). The lasting impact this had on Islam is obvious from the fact that religious-minded emperors like Aurangazeb, even though they ruled vast empires, worked to earn their livelihood – something observed with great astonishment by Europeans who had never known any ruler of this sort. In the early Christian version, Origen argued that not only were all souls created equal, but they would again become equal at the end of time, since all would ultimately achieve deliverance, as in *karma-samskāra*, and there would be a time when God would be all *in* all.

This notion of an immanent God was also essentially a celebration of the creativity of life. Man creates the future cosmos (at least a tiny part of it), just because God is in Man (and also other living creatures). All people are equal, just because all people are equally parts of one God. Since these notions involved a celebration of creativity, they were associated with what have been called "fertility cults", such as the worship of Bacchus or Dionysius. In India, various Tantric schools have many similar practices. The relation of equity to creativity is well brought out by the Lokayata festival, today known as Holi. On the one hand it is related to the harvest and is thus a celebration of creativity. The custom of throwing color on people was intended to erase the social distinctions that are displayed by means of clothes, and in fact to erase all individuality. The custom of taking bhang (marijuana) was intended to further creativity by heightening sexual passion.

Inequity as the Basis of Linear Time

After Constantine, this belief in the equity of all souls stood in the way of the political goals of the church, which now viewed the world from the imperial perspective of the Roman state: if all souls would be saved anyway what was the advantage to be gained by turning Christian? If God was within man, where was the need to fear God, and be obedient to the priest? Hence, theologians like Augustine proposed to erase equity and erect a transcendent God who would judge people and establish a simplistic moral division between good (Christians) and bad (non-Christians). In the revised picture proposed by state Christianity, all souls were NOT equal, so not all souls were eventually saved. Instead God established a permanent inequity in the world, sending some souls (those of good Christians) to heaven (forever), and other souls (non-Christians) to hell, as described in gory detail by Dante, for example. Reincarnation was accordingly changed to resurrection – life after death, just once.

Because the earlier notion of soul depended upon a view of life after death deriving from the belief in quasi-cyclic time, time beliefs were also compelled to change with this changed notion of the soul and of life after death. Time beliefs changed from qausi-cyclic time to linear apocalyptic time: the world, as conceived by Augustine, began a few thousand years ago, and would soon come to an end. The notion of the soul became metaphysical.

Thus, the question of linear versus cyclic time is an issue that lies at the very foundation of Christianity (and the related historical notion of the West, as in Toynbee's classification, used more recently by Huntington). Rejection of that view of (apocalyptic) linear time would amount to a denial of the entire religious ideology of state Christianity, as it is understood today. This explains the significance and importance to the West of the competitive stereotype of linear time versus cyclic, directed as much against early Christianity as it is directed against non-Western views of time.

The Western Misrepresentation of Quasi-Cyclic Time as Supercyclic

Augustine argued against Origen's view, by misrepresenting "cyclic" time as eternal recurrence or a state of affairs where deliverance was available to none. He asserted that the cosmos would recur exactly, so that even Jesus Christ would be repeatedly reborn and repeatedly crucified, so that no one could be saved. "Heaven forbid that we believe this, for Christ having died once for our sins, rising again, dies no more". Augustine then rejected this state of affairs on the grounds of "fatalism" (which, he quibbled, was different from "determinism").

This was certainly a misrepresentation of non-Western views, where deliverance from the cycle of birth-death-rebirth was not only held to be possible, it was regarded as the ultimate aim of life. This was also a misrepresentation of Origen who explicitly stated:

> And now I do not understand by what proofs they can maintain their position, who assert that worlds sometimes come into existence which are…in all respects equal. For…then it will come to pass that Adam and Eve will do the same things which they did before: there will be a second time the same deluge…. So therefore it seems to me…that a diversity of worlds may exist with changes of no unimportant kind…in that age [world] which preceded this, Christ did not suffer…. (*De Principis*, Book II, chapter III.4-5)

Augustine's misrepresentation of "cyclic" time may be presented thus: time was thought to be quasi-cyclic, whether in *karma-samskāra* or in Origen's teachings; however, Augustine misrepresented quasi-cyclic time as supercyclic time – a situation (of "eternal and exact recurrence") where no change is possible in the cosmos, which repeats mindlessly like a stuck record (this "repetition" being in some implicitly assumed notion of increasing time, external to the cosmos, perhaps in the mind of God). Most Western thinkers have fallen into the same Augustinian trap of confounding "cyclic" time with "eternal recurrence" because they lacked even the words required to make a distinction between different varieties of cyclic time.

Therefore, Augustine's misrepresentation of Origen's notion of "cyclic" time has confused a long line of Western thinkers like Nietzsche, who founded an entire philosophy on this misunderstanding of "cyclic" time as supercyclic time or "eternal recurrence of the same". The same confusion between quasi-cyclic time and eternal recurrence can be found in T. S. Eliot, or in Mircea Eliade's *The Myth of the Eternal Return*.

Starting from Newton, the same confusion about "cyclic" time persists in scientific theory to this day. For example, Stephen Hawking and G. F. R. Ellis, in their *Large Scale Structure of Spacetime,* argue against closed time loops (a third variety of partially cyclic time, distinct from quasi-cyclic time and super-cyclic time) repeating exactly Augustine's mistaken arguments. The first step of the argument confounds any sort of cyclicity with eternal recurrence, and the second step rejects eternal recurrence on grounds of fatalism. More recently, arguments in the scientific literature related to the Grandfather paradox of time travel, which involves a loop in time, have again endlessly repeated Augustine's wrong arguments. The confusion between quasi-cyclic time and eternal recurrence seems to reverberate eternally in Western thought: "cyclic" time represents "eternal recurrence" hence fatalism, and should be rejected. On the contrary, as this author has pointed out, such closed loops in time, being causally inexplicable from the past, are the way to have spontaneity, or creativity, within the frame of current physical theory.

Thus, the Western stereotype of non-Western views of time involves involves a very deep-seated and long-standing confusion about the nature of time within Western thought, starting from Augustine and stretching down to people like Newton, Einstein, and Hawking.

There are a few other aspects of non-Western views of time that deserve at least a brief mention.

Discrete Versus Continuous Time

First, consider the issue of discrete versus continuous time. The belief that time is a continuum is forced in present-day physics, as we have seen, only by the Western understanding of the calculus, based on an idealistic understanding of mathematics. However, the calculus that developed in India incorporated a different understanding of mathematics, that could be called a realistic understanding. The difference between the two may be explained with reference to the Buddhist denial of the existence of the soul. The Buddhists (especially followers of Nāgārjuna's *śūnyavāda*) maintain that between two instants of time, an individual changes, and there is nothing "essential" in the individual that remains the same. In common parlance, and for practical purposes, we neglect or zero the differences as inconsequential, or non-representable, due to a paucity of names.

Let us now apply this understanding to a number like π, which denotes the ratio of the circumference of a circle to its diameter. No matter how we try to express this number, it cannot be specified – that would require a supertask. In idealistic (formal) mathematics, it is asserted that there really is such a number, although any actual representation of it will always only be approximate or erroneous. In realistic mathematics it would be asserted that calculations can only be done with an actual representation and not an idealized one. There is a paucity of names, and therefore we use a representation appropriate for a given practical purpose, zeroing certain things treated as non-representable. The subtle difference between the two positions is brought out very clearly in the representation of such numbers on a computer; the actual numbers (floating point numbers) do not follow the same rules or "laws", such as the associative law for addition that the ideal "real" numbers are supposed to obey.

This leads to a fundamentally different understanding of "infinitesimals" (as non-representable quantities discarded in a calculation), which presented such a problem for Newton and Leibniz. However, all practical conclusions drawn from the calculus use realistic mathematics and computation, rather than idealistic mathematics. Therefore, the idealistic point of view, which forces time to be a continuum in physics, involves the superposition of "extra baggage" from Western metaphysics, and there is no real need to believe that: time may well be regarded as discrete or atomic, provided one does the calculus with a different philosophy of mathematics. The point here is not to argue that time is, in fact, discrete, but rather that the discreteness or continuity of time should not be fixed purely from mathematical and metaphysical considerations, since these metaphysical considerations could be fundamentally different in the non-West.

Atomically Structured Time and Quasi Truth-Functional Logic

The second question concerns the link between time beliefs and logic. Time may be related to logic through Wittgenstein's notion of logical worlds: the state of the physical world at an instant of time can be specified by specifying all the statements that are true at that instant of time. In the West it has been believed that if A is true at an instant of time, then its negation ∼A cannot be true at that very instant. Certainly there are schools of thought in the non-West which also subscribe to this belief, but it is not universal. Buddhist and Jaina logics permit both A and ∼A to be true at an instant of time. This involves the concept of an atomically structured time. The classical way to explain this would be to think of an instant of time as a microcosm. A modern explanation for this state of affairs can be provided using microphysical loops in time.

Imagine that one has a time machine, and that one puts Schrödinger's cat (now dead) on board the time machine and sends it back to the time of Schrödinger. The events here described from a future perspective would actually have been observed by Schrödinger somewhat differently: for Schrödinger, the "observed" sequence of events would have been that time spontaneously and inexplicably split into two streams (both part of this world), in one of which the cat is alive, and in the other it is dead. (At the microphysical level, one can actually "see" a somewhat analogous phenomenon of a photon or a particle of light splitting into an electron-positron pair, which may later recombine to produce back a photon. The positron has exactly the properties of an electron travelling back in time, so the process can also be described as an electron executing a closed circuit in time.) These two streams of time, witnessed (or rather inferred) by Schrödinger, are NOT "parallel" worlds, for the two worlds do meet, and the two cats would coalesce back into a single cat at the time we put the cat into the time machine.

In place of imaginary time machines, one can construct a more realistic desktop model involving parallel computing, although understanding this requires a little more technical knowledge. In parallel computing, a single process executing on parallel processors may be in multiple states at a "single instant" of time. Needless to say, "parallel" is a bit of a misnomer, since it is an essential feature of parallel computing that the processors (logical worlds, in the Wittgensteinian sense) and processes communicate with each other, and that they branch and collapse. Time, so to say, acquires a structure, and it is necessary to take into account this structure to understand the semantics of formal parallel computing languages.

Microphysical closed time loops enable us to understand how an atom of time can nevertheless have a structure, in the sense that multiple logical worlds are attached to a single instant of time. This structure is manifested not by further subdivision of the atomic instant, but by a change of logic. In such a situation of an atomically structured time, it is perfectly possible to have both A and not-A valid at a single instant of time that cannot be further decomposed.

This notion of an atomically structured time or a structured instant is the basic unit of reality in Buddhism. It leads to the alternative notion of "causality" in Buddhism, called *paticca samuppāda*, or "conditioned co-origination". The present is not the cause of the future, but the future cooriginates, conditioned by the past. *Paticca samuppāda* is identified by the Buddha as the key to his Dhamma. Thus, the use of a logic of four alternatives in Buddhism is not incidental to Buddhism but is integrally linked to its worldview, for it is only through an understanding of the causes of *dukha* that one can remove it.

Ontically Broken Time

The common terminology of the laws of physics – for example, Newton's laws of motion – is related to the theological idea that creation was a one-time process and that subsequent states of the cosmos were controlled by God using laws. This idea of a clockwork cosmos is denied in many non-Western systems of thought. Al-Ghazālī, argued from a different perspective, where the world is continuously created by God. In this situation, any causal connection becomes a restraint on the powers of God; al-Ghazālī denied the existence of causal connections. He conceded that there are observed regularities in the cosmos, but he explained them as arising from force of habit. God habitually creates smoke with fire; he is not obliged to do so. Of course, one does not know on what time scale God changes habits, but it could be imagined that the cosmos is such that not only would physical theories change, but physics itself would change, over a time scale of, say, a thousand years.

More to the point, this helps us to see the historical evolution of the idea of the laws of God. Thus, al-Ghazālī was speaking about an immanent God, the apparent restrictions on whose powers were all too obvious. When this was taken over in the West, as by John Scotus Duns, it created a problem, because it was supposed (at least by the opponents of this point of view) that this description concerned a transcendent God. Under those circumstances, God would become a terrible tyrant, since one would never know what to expect next. Accordingly, God's intervention was toned down, and his role limited to instituting laws. This led eventually to superlinear time.

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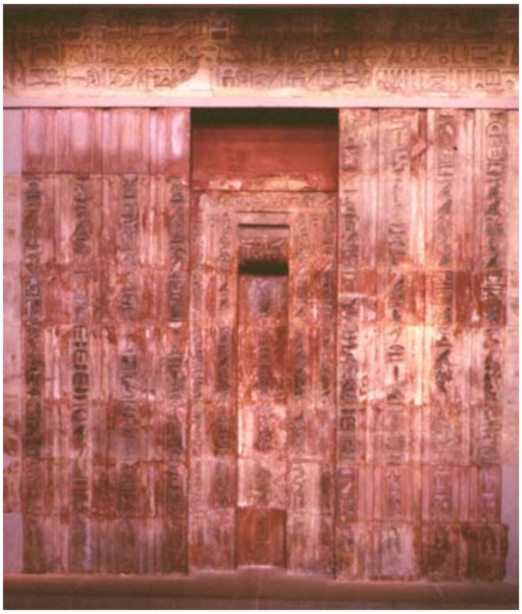
Tombs in Ancient Egypt

Aidan Dodson

An Egyptian tomb ideally comprised two basic parts. One was intended to house the body for eternity; the other was to act as the interface between this world and the next. These two elements could lie close to one another or could be separated by some considerable distance; they could also be of various constructional types and materials. However, the fundamental distinction remained between the mortuary chapel, or offering place, open to the public, and the burial chamber, intended to be sealed for eternity.

The public element usually focused on a stela, an inscribed slab that provided a point at which the two worlds met. It might be of simple form, bearing a depiction of the deceased (and perhaps his or her spouse) receiving offerings of food and drink, together with a ritual formula that guaranteed their eternal provision. On the other hand it might be an elaborately panelled 'false door' (Fig. 1), making explicit the stela's role as a portal between the worlds. In certain cases a statue of the dead person might replace or supplement the stela.

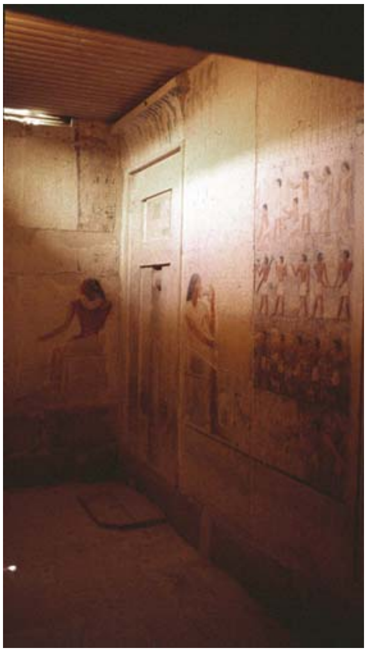


Tombs in Ancient Egypt. Fig. 1 A typical false door stela of the Old Kingdom (British Museum EA682) belonging to Ptahshepses (ca. 2425 BCE) Photo by author.

In many tombs the offering place comprised simply the stela, standing exposed, or with a very basic shelter carved out of the rock or built in brick or stone. However, in other cases the offering place was housed in a far larger structure, which could in turn be extensively decorated (Fig. 2). This structure may be referred to as a mortuary chapel or a mortuary temple, the latter term being generally used for royal examples.

For much of Egypt's history, the decoration of such structures was concerned with food production, other motifs taken from the agrarian world and the experiences of the deceased. In royal cases, this could include scenes of the gods and events of the reign. Tableaux in private chapels are often referred to as 'daily life' scenes and provide an important source for our understanding of life in ancient Egypt. Their primary role was clearly to recreate magically the world the deceased had once enjoyed, as well as providing a further source of eternal sustenance. It seems likely, however, that they had other more esoteric significance, linked with concepts of regeneration and rebirth in the next world. From around 1250 BCE, these 'daily life' scenes tend to be replaced by others of purely ritual type, with images of the gods and extracts from the various Egyptian funerary 'books' that aided the dead person in his or her posthumous destiny.

As already noted, the form of the offering place varied. At one extreme, those of kings could be huge temples, either freestanding or, prior to the middle of the second millennium BCE, attached to a pyramid. Prior to the appearance of the pyramid, royal tombs seem to have had a simple offering place adjacent to the burial chamber, and a large rectangular enclosure up to 1.5 km away. A mound of rubble or some other structure may have topped the burial place itself. At the beginning of the Old Kingdom (ca. 2650 BCE), these separate elements were united in a single location, in the Step Pyramid complex of King Djoser at Saqqara. For perhaps the first time, all parts were built of stone, and a low square structure over the burial place was soon extended to form the basis of a six-stepped pyramid, the first of its kind (Fig. 3).



Tombs in Ancient Egypt. Fig. 2 The false door of Ptahhotep at Saqqara (ca. 2350 BCE) lies within a highly decorated chapel. Photo by author.

Only the very earliest pyramids were stepped, perhaps to provide a stairway to heaven for the dead king. They were soon replaced by smooth-sided structures ('true pyramids'), apparently intended as a recreation of the sun's rays, along which the monarch might make his way to join with the sun god (Fig. 4). The very first step pyramids were surrounded by large rectangular enclosures holding ritual buildings (Fig. 5). However, these were soon superseded by a smaller enclosure with a mortuary temple on the east side of the pyramid. From this a causeway led to a 'valley temple' on the edge of the desert (Figs. 6 and 7).

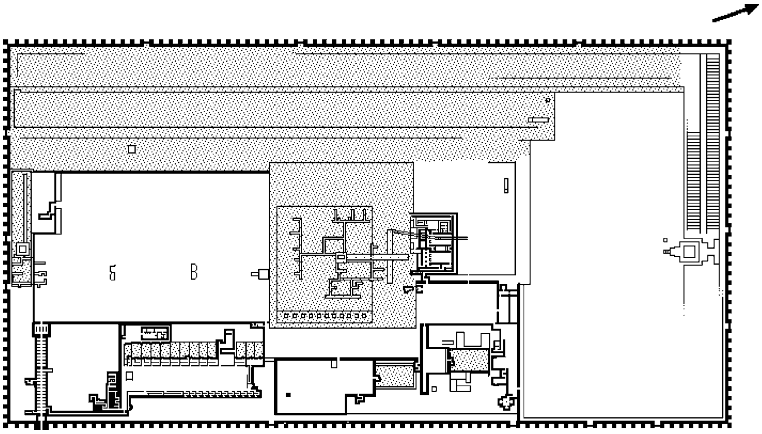
The free-standing temples that were adopted by the kings of the New Kingdom (1550–1070 BCE) after the royal abandonment of pyramids were all but indistinguishable from contemporary temples of the gods, the differences being in detail only (Figs. 8 and 9). Unlike earlier mortuary temples, the king's spirit now shared the temple with Amun, the King of the Gods, and the sun god, Re, each of whom had his own separate sanctuary within the temple.

Private individuals' mortuary chapels fall broadly under three headings. One type is built against or within *mastabas*, stone or brick structures shaped like low benches ('mastaba' means 'bench' in Arabic). They are used throughout Egyptian history at sites with a flat basic topography, although the best-known date to the Early Dynastic Period and Old and Middle Kingdoms (ca. 3000–1700 BCE).

Mastabas of the earliest times usually had a panelled exterior, but from the Old Kingdom onwards they tended to have flat, slightly sloping, sides, although panelling is occasionally found down into the Middle Kingdom (2100–1700 BCE). Chapels range from a simple niche at the southern end of the eastern face, holding the stela, to a complex of a dozen or more decorated rooms occupying much of the interior of the mastaba. Most usual is an offering place with one or two rooms (Figs. 10–12, 15).

Tombs in Ancient Egypt. Fig. 3 The first pyramid – the Step Pyramid at Saqqara. Photo by author.

Tombs in Ancient Egypt. Fig. 4 The finest examples of the true pyramid lie at Giza, belonging (left to right) to Kings Menkaure, Khaefre and Khufu (ca. 2550–2475 BCE). Photo by author.

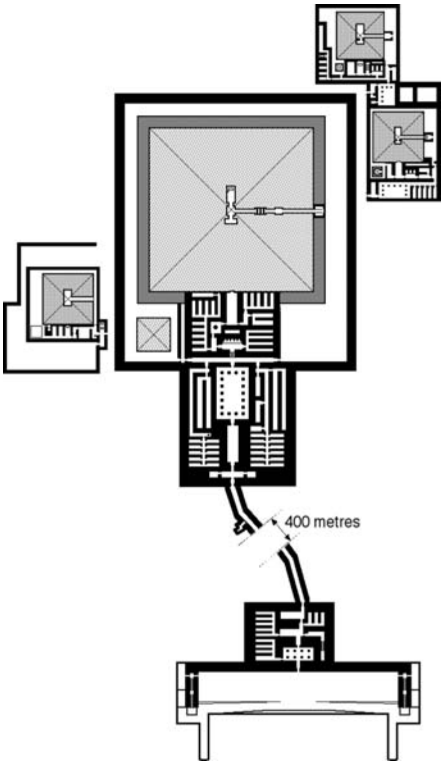


Tombs in Ancient Egypt. Fig. 5 Plan of the Step Pyramid complex, showing the great expanse of ritual buildings. Plan by author.

Tombs in Ancient Egypt. Fig. 6 Typical of later pyramids is that of Sahure (ca. 2465–2450 BCE), with a mortuary temple on the east side. Photo by author.

The next type of mortuary chapel is also employed on flat sites, but comprises a freestanding building without an associated mastaba. Once again, these can vary considerably in size and elaboration, from little more than a shed around the stela to a miniature temple. The latter seem to appear first late in the Eighteenth Dynasty and are referred to as 'temple-tombs' (Fig. 13).

The final form of mortuary chapel is that which is cut into a rock face (Fig. 14). Such offering places first appear around 2500 BCE at Giza, and are found throughout the rest of Egyptian history. Plans are almost infinitely variable, although a number of fairly standardised plans are to be seen at Thebes during the New Kingdom (1550–1070 BCE). In particular there is the T-shaped tomb, with a broad but shallow hall running across the axis, and a long corridor running from the middle of its back wall to the offering place, deep in the rock. This basic form could be greatly elaborated by the addition of columns and further chambers – one had no fewer than 70 columns.



Tombs in Ancient Egypt. Fig. 7 This shows the layout of the whole complex of Pepy II (ca. 2290–2180 BCE); the small pyramids belonged to his wives. Plan by author.

Of course, this division is purely for convenience, and many tombs exist that are a combination of more than one category. In particular, rock-cut mortuary chapels could have freestanding courtyards built in front of them (Figs 17 and 18). Particularly elaborate examples date to the Saite Period (663–525 BCE). In addition, after the abandonment of pyramids by kings, miniature examples often appeared above private sepulchres, of both built and rock-cut designs.

The burial chamber and its associated elements are collectively known as the 'substructure'. The two key types are those approached via a vertical shaft and those accessed by sloping passage or stairway. A further consideration is whether the substructure has been tunnelled out of the living rock, or whether it has been constructed out of stone or brick in a cutting in the desert surface and subsequently covered over. There are, however, tombs that use more than one approach to various elements of their substructures.

In the vast majority of Egyptian tombs the substructure lay close to, or directly under, the offering place. Many Old Kingdom mastabas had shafts descending from their roofs to burial chambers in the rock below (Fig. 15), while royal pyramids usually had their burial chamber under the centre of the monument, approached via a sloping corridor from the centre of the north face of the pyramid. In rock-cut mortuary chapels, sloping passages are found in the earliest examples, but later shafts are used as well.

Tombs in Ancient Egypt. Fig. 8 The earliest surviving New Kingdom royal mortuary temple is that of Queen Hatshepsut (ca. 1472–1457) at Deir el-Bahari. Photo by author.

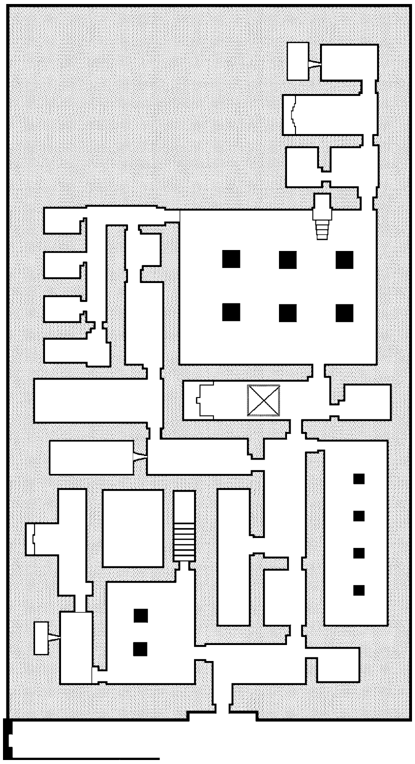
Tombs in Ancient Egypt. Fig. 9 Of rather different appearance, but with the same purpose is the temple of Ramesses III (ca. 1185–1153 BCE) at Medinet Habu. Photo by author.

Tombs in Ancient Egypt. Fig. 10 The entrance to the now-ruined chapel of the panelled brick mastaba of Nefermaat at Meidum (ca. 2550 BCE). Photo by author.

Tombs in Ancient Egypt. Fig. 11 A group of stone mastabas at Giza (ca. 2430 BCE). Photo by author.

Occasionally, the substructure lies some way from the offering place. The best examples of this are the royal tombs of the New Kingdom at Thebes, where the mortuary temples lay on the edge of the desert, but the tomb chambers were up to 2 km away in a desert valley. This is now known as the Valley of the Kings, and also held the burial chambers of a handful of highly placed nobles, whose rock-cut mortuary chapels lay a similar distance away.

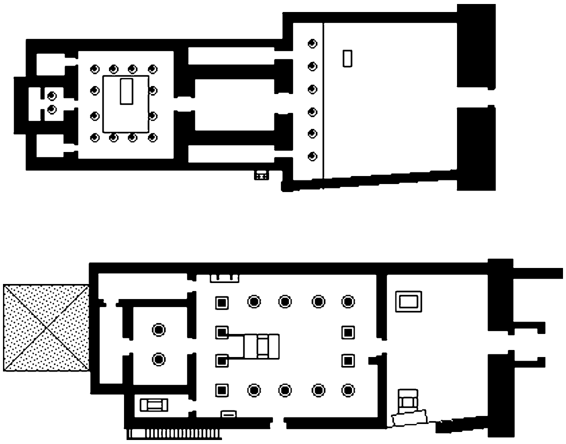
Substructures took a variety of forms, ranging from a single chamber and approach shaft/corridor, to a long sequence of corridors, pits and halls. Some included special security features, with sliding trap doors, hidden entrances, and/or burial chambers cut from single blocks of stone, closed with the aid of a 'hydraulic' system using sand. Such features were first employed during the late Twelfth Dynasty (ca. 1800 BCE), and then revived over a millennium later, during the Saite Period.



Tombs in Ancient Egypt. Fig. 12 The most elaborate chapel within a mastaba is that of Mereruka (ca. 2340 BCE) at Saqqara. Plan by author.

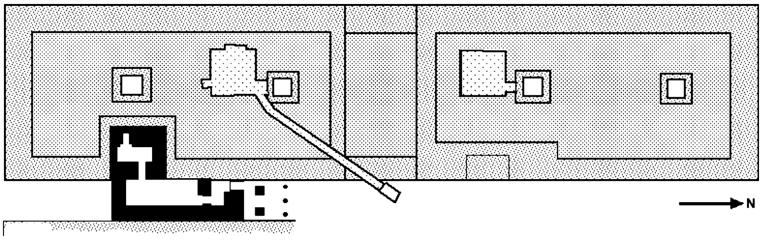
Royal tombs were not surprisingly amongst the sepulchres with the most elaborate substructures, although certain private examples, particularly of the Saite Period, exceeded even them. Many earlier pyramids had a standardised substructure, built of stone in a shallow cutting, with a group of three chambers reached by a long corridor. This was blocked by three vertical portcullis slabs of granite (Fig. 7). From the middle of the Middle Kingdom, however, changes were brought in to increase security. Entrance locations became random, and the aforementioned security arrangements introduced.

The security imperative probably also lay behind the separation of the royal burial chamber from the mortuary chapel early in the New Kingdom. The Valley of the Kings tombs generally take the form of a set of

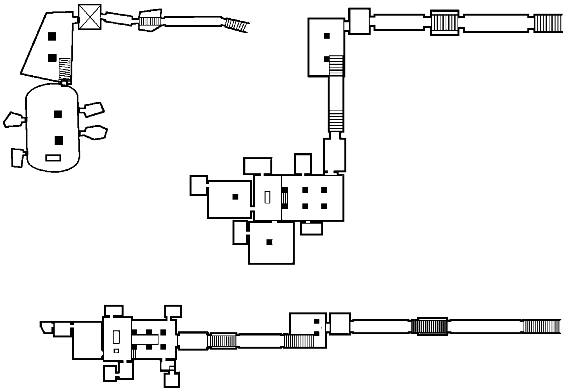


Tombs in Ancient Egypt. Fig. 13 Plans of the 'temple-tombs' of Maya and Tjia at Saqqara, ca. 1340–1240 BCE. Note the pyramid attached to the rear of the lower sepulchre. Plan by author.

Tombs in Ancient Egypt. Fig. 14 A classic group of rock-cut mortuary chapels are at Aswan, dating between ca. 2400 and 1850 BCE. Photo by author.



Tombs in Ancient Egypt. Fig. 15 Plan of the tomb of Kawab at Giza (ca. 2530 BCE), showing the burial shafts descending through the superstructure and the chapel built partly within and partly outside the mastaba. Plan by author.

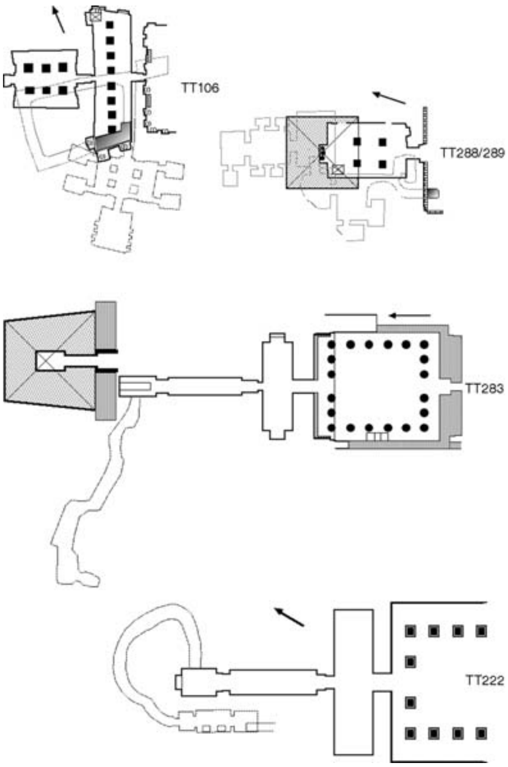


Tombs in Ancient Egypt. Fig. 16 Plans of the tombs of Kings Thutmose III, Amenhotep III and Horemheb in the Valley of the Kings, showing the evolution from a ‘bent’ to a straight plan between ca. 1450 and 1300 BCE. Plans by author.

passages and stairways, leading to a pillared antechamber, and finally to a pillared burial chamber. A shaft in the floor interrupted progress down the tomb, probably with a dual role of hindering thieves and preventing storm water’s penetrating the inner rooms (Fig. 16).

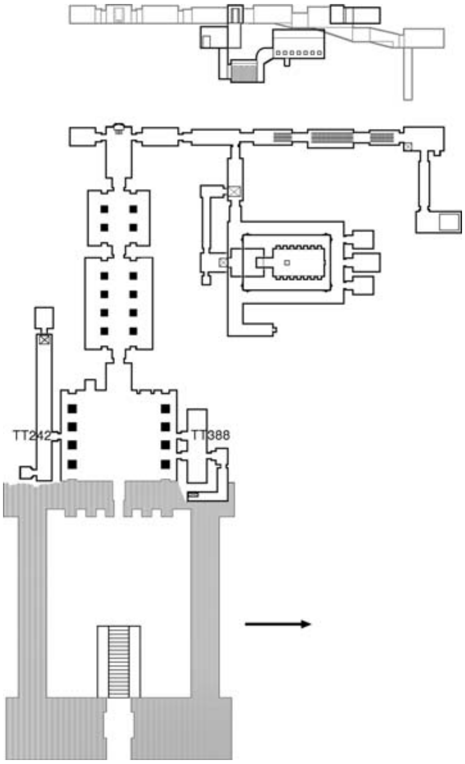
In contrast to the mortuary chapel or temple, which almost always had some form of decoration, the substructure was usually completely plain. The principal exceptions were the royal tombs of the late Old Kingdom and the New Kingdom onwards, and a handful of private sepulchres of the Sixth Dynasty, Middle Kingdom, New Kingdom and Saite Period. In the late Old Kingdom, royal burial apartments were adorned with the *Pyramid Texts*, magic formulae intended to aid the king in the next world. They are the ancestors of a whole series of ‘books’ that formed the basis for all later substructure decorations.

Royal tombs of the New Kingdom and later were principally adorned with various heavily illustrated compositions relating to the sun god’s nocturnal journey through the underworld, in which the dead king would participate (Fig. 19). At first these works were a royal prerogative, but by Saite times they could also be found in private tombs as well, which also revived the ancient *Pyramid Texts*.



Tombs in Ancient Egypt. Fig. 17 Plans of the private tombs of Paser, Setau, Roma-Roy and Heqamaatrenakhte at Thebes during the middle of New Kingdom (ca. 1300–1150 BCE), showing the relationship between the mortuary chapel, in some cases pyramid, and the substructure. Plans by author.

The rare Old Kingdom decorated private burial chambers generally had illustrated lists of offerings on their walls. This was also the case in the Middle Kingdom, but in the New Kingdom the main decorative composition was the *Book of Coming Forth by Day* – better known as the *Book of the Dead*. This was essentially a guidebook to the next world, and was more usually found on a papyrus placed alongside the mummy. Extracts are also found in mortuary chapels of the Nineteenth Dynasty and later.



Tombs in Ancient Egypt. Fig. 18 One of the largest and most elaborate tombs in Egypt belonged to the priest Pedamenopet (ca. 600 BCE). It was partly built of brick and partly rock-cut, with an extremely elaborate substructure. The burial chamber was carefully concealed, and was approached from below. Plan by author.

Following the Macedonian and Roman takeovers of the country, Egyptian-form tombs were supplemented by those in the Classical tradition, in particular at Alexandria and in other areas with high levels of European settlement. However, even these sepulchres often included Egyptian features, especially in their decoration, where the native gods often appeared. A key difference between the two mortuary traditions was the blurring of the previous rigid distinctions between the chapel and the burial place. In Classical tombs the body was placed in a sealed loculus in the wall of a generally accessible catacomb that might include both a chapel and a room for funerary feasts.

See also: ►Mummies

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Tombs in Ancient Egypt. Fig. 19 The Book of the Earth, one of the numerous compositions found on the walls of New Kingdom royal tombs. Here it is seen in the burial chamber of Ramesses VI (ca. 1141–1133 BCE).

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Tongren Zhenjiu Shuxue Tujing

RICHARD BERTSCHINGER

The *Tongren Zhenjiu Shuxue Tujing* (Illustrated Canon of Acupuncture Points based upon the Bronze Figure) was written by Wang Weiji, and published in AD 1026. It has been a baseline in the identification of acupuncture points ever since. It is used not only in Chinese medicine, but also in acupressure as developed recently in the West, in *shiatsu* (pressure point massage) in Japan during this century, and in all acupuncture-related disciplines.

By the Song Dynasty (AD 960–1126), after much copying and recopying, the locations of the points and channels had become confused. Because of this and the greater stability brought about by the Song reunification of the empire, the medical scholar Wang Weiji reorganized and collated all the then available material in order to locate and define the points precisely.

He produced a book which very quickly became the authoritative text throughout the country. It gave very detailed and accurate information concerning the points, the channels, the depths and effects of needling. The total number of points named in the *Huangdi Neijing* (Yellow Emperor's Canon of Medicine) had been 160; in the *Zhenjiu Jiayi Jing* (A–Z of Acupuncture and Moxibustion) it was 349. But now it was raised to 354. Not long afterwards, the full text of this book was cut onto two stone tablets, each some 2 m high and 7 m in length, which were erected in the Song capital, Kaifeng, where they could be read by everyone, or where ink-impressions could be made from them.

At the same time Wang Weiji directed the casting of two life-size bronze figures – hence the title of his book – which were completed in 1027.

These bronze figures are the very earliest of their kind. They were hollow and had the exact locations and names of the acupuncture points marked on their surface. It is noted in the Song histories that the purpose of the figures was for them to be covered in beeswax and then filled with water. When a student palpated and punctured a point correctly, a stream of water would flow out, reminiscent of the energy stream (or *qi*) tapped by that particular point.

The later history of these figures and tablets is also revealing. After two hundred years, when the Yuan Dynasty moved the capital to what is now Beijing, the bronze figures and tablets were also moved, to take pride of place in the temple at the new Imperial Medical College. However, much use had been made of the figures, and the tablets were so worn that they were indecipherable. Reproductions were therefore made again. During excavations from 1965 to 1971 in Beijing, fragments of the original Song tablets were discovered, and their texts shows that the tradition has been faithfully and accurately preserved to the present day. This book is used as the foundation text for the listing of points in the *Essentials of Chinese Acupuncture* (Beijing 1980) and other texts which have all been recently produced in China and which are aimed at the interested acupuncture audience in the West.

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Tools Used in Ancient Egyptian Construction

JAMES A. HARRELL

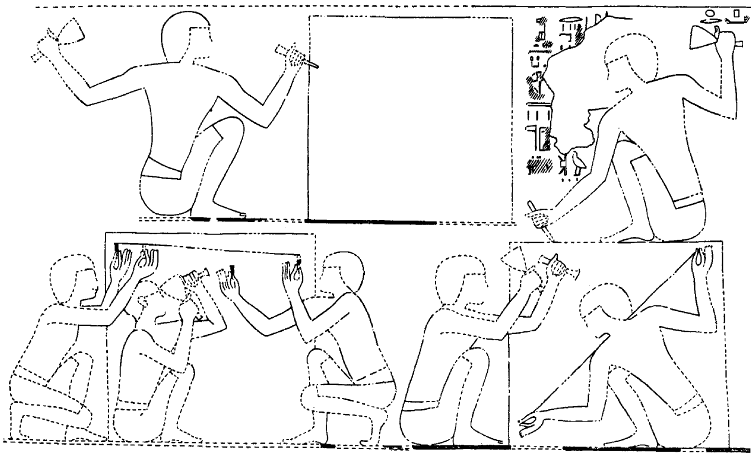
Building Materials

Most ancient Egyptian buildings were constructed of either mud bricks with wood elements or waddle-and-daub walls of intertwined poles packed with mud. These include all the houses and even the royal palaces. In the better-built structures, mud bricks were used for the foundations and walls with wood planks and poles employed for most everything else, including door and window frames, doors, window shutters, vertical supports (pillars) for roofs and upper floors, and horizontal supports for the mud-brick walls. Stone was also sometimes used in these buildings wherever extra strength and durability were required, such as for door thresholds and pillar bases. The only buildings constructed largely or entirely of stone were the temples and freestanding tombs (pyramids and mastabas [tombs]), although some of these were also built of mud brick, and many stone temples were surrounded by massive mud-brick walls.

The construction tools considered here were in use during Egypt's Dynastic period (Dynasties 1–30), which ranged from about 3000 to 332 BCE (Table 1). The subsequent Greco-Roman period is excluded because many of the tool designs (and construction practices) were imported from the Greeks and Romans. Although there are no ancient Egyptian texts describing the use of construction tools, many of the tools themselves have survived, and there are also numerous carved reliefs and painted scenes on the walls of tombs showing the tools in use (Petrie 1917; Clarke and Engelbach 1930; Arnold 1991; Gale et al. 2000; Kemp 2000). Two such tombs are especially noteworthy in this regard, those of (1) Ti, an overseer of pyramids and temples under three 5th Dynasty kings (late Old Kingdom) at Saqqara near Cairo (Epron 1939; Wild 1966) and (2) Rekhmira, a vizier under two 18th Dynasty kings (early New Kingdom) at Qurna near Luxor (Davies 1943). It is the art in these tombs that supplied the representations of tool use in Figs. 1–17. Another source of information

Tools Used in Ancient Egyptian Construction.
Table 1 Ancient Egyptian chronology

- Late Predynastic Period (3200–3000 BCE): Dynasty 0
- Dynastic or Pharaonic Period (3000–332 BCE): Dynasties 1 to 30
  - Early Dynastic Period (3000–2686 BCE): Dynasties 1 and 2
  - Old Kingdom (2686–2160 BCE): Dynasties 3 to 8
  - First Intermediate Period (2160–2055 BCE): Dynasties 9 to early 11
  - Middle Kingdom (2055–1650 BCE): Dynasties late 11 to 14
  - Second Intermediate Period (1650–1550 BCE): Dynasties 15 to 17
  - New Kingdom (1550–1069 BCE): Dynasties 18 to 20
  - Third Intermediate Period (1069–664 BCE): Dynasties 21 to 25
  - Late Period (664–332 BCE): Dynasties 26 to 30
- Greco-Roman Period (332 BCE–395 AD)
  - Ptolemaic Period (332–30 BCE)
  - Roman Period (30 BCE–395 AD)

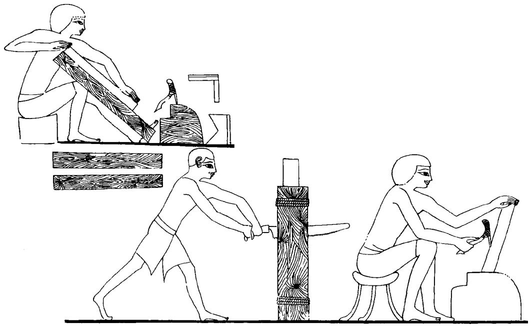


Tools Used in Ancient Egyptian Construction. Fig. 1 Stoneworkers using mallet-struck chisels, leveling rods (lower left), and a measuring cord (lower right). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 52).

comes from experimental archaeology, where facsimiles of ancient tools are made and then used to test their efficacy in various applications and materials (Stocks 2003; Solenhofen website).

Measuring Tools

Construction, especially of the more elaborate stone structures, required the use of a variety of measuring tools, including ones for determining distance, slope, and flatness. For distance, the Egyptians had "cubit rods" and "measuring cords." The "cubit" was a standard unit of distance that varied slightly during the Dynastic period but averaged 52.5 cm. It was divided into seven "palms," each of which was further subdivided into four "fingers." The working cubit rods were carved from wood, and some could even be folded along hinges. Measuring cords were used to mark off both short and especially longer distances, and these were subdivided by knots tied at fixed multiples of cubits (Fig. 1).



Tools Used in Ancient Egyptian Construction. Fig. 2 Woodworkers using a saw (center), adzes (lower right and upper left), and a straightedge (or perhaps a cubit rod; upper left). Note the builder's square just to the right of the adze (upper left). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 55).

Squared edges and corners were achieved through the use of a "builder's square," which consisted of two straight lengths of wood joined at their ends to form a right (90°) angle (Figs. 2 and 7). The "square level" combined a builder's square with a "plumb bob." It had two perpendicular sides of equal length that were joined by a crosspiece. At the apex, where the two joined sides met, there was an attached cord with a plumb bob suspended from the other end. The conical plumb bob was typically carved from stone. In use, the square level was placed upright on (vertical and perpendicular to) a surface, resting on the free ends of its two sides. By noting where the cord with the plumb bob lay on the crosspiece, the slope of the surface could be ascertained. Plumb bobs suspended from long cords were used to mark straight lines on vertical surfaces, check the verticality of walls, and measure vertical distances. A tool called a "plumb rule" was also employed to determine verticality. This consisted of a flat wood plank with two short shelves of equal depth at one end. A cord was attached to the end of the plank, just above the shelves, and this was threaded through a hole in the top shelf, exiting at its outer edge. A plumb bob was suspended from the cord's other end. To use the plumb rule, the back of the plank was pressed against a surface with the end bearing the attached cord and shelves oriented upward. The cord with the plumb bob was draped over the bottom shelf, and if the surface was vertical then the cord would just touch the shelf's outer edge.

"Marking cords" were employed to draw straight lines on a surface. The cord was first dipped in a colored paint or powder (usually made from red ochre) and then pulled taunt across the surface. By flicking the cord against the surface, a straight line was marked off.

A set of "leveling (or boning) rods" was used to ascertain the flatness of a stone surface (Fig. 1). The set's three or four short wood rods were of identical length, and two of these were joined at their tops by a cord with the others left unattached. Two workers, each holding one of the joined rods, would place their rods upright (perpendicular to) the surface and then pull the cord taunt. With their free hands, or with the assistance of a third worker, the loose rods were placed upright on the surface and moved along the stretched cord. Wherever one of these rods fell below or rose above the cord, a departure from flatness was indicated. Areas that were too high were probably marked with colored paint or powder to show where additional dressing of the surface was needed. The degree of flatness of a small surface could also be determined with a "straightedge," which was a long piece of wood with a straight edge (Fig. 2).

Cutting Tools

Stone vs. Metal

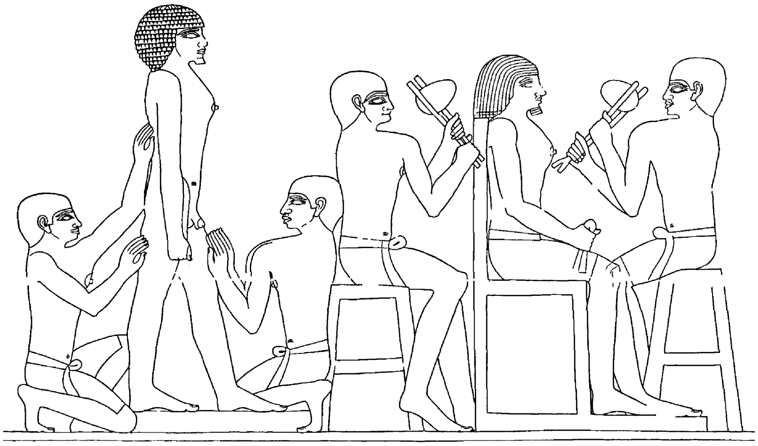
The first tools used in ancient Egypt, and volumetrically the most common ones employed throughout the Dynastic period, were made of stone. Tools requiring a hard, sharp edge or point were fashioned from chert (also known as flint), a rock consisting of microcrystalline quartz. These were used to cut soft stones (limestone, sandstone, travertine, and rock gypsum) as well as wood. Hard stones with good impact-fracture resistance (notably anorthosite gneiss, dolerite, and siliceous [quartz-cemented] sandstone or "quartzite") were employed for pulverizing and grinding the hard stones, including anorthosite gneiss, basalt, granite, granodiorite, metagraywacke, and siliceous sandstone among a few others.

Copper tools, like those of stone, predated the Dynastic period. Because copper is a very soft metal, it could only be used to cut wood and soft stones, and being much costlier than stone, it was used sparingly for tools and then just for the more important projects. The much harder bronze metal (copper alloyed with tin) was first introduced during the Middle Kingdom and became the predominant material for metal tools beginning in the New Kingdom. Even though much harder than copper, bronze was still too soft to use on hard stones. Iron-bearing tools first appeared toward the end of the New Kingdom and came into common use during the Late period. Although usually described as consisting of "iron," these tools were actually made from either a primitive kind of steel (iron alloyed with carbon) or case-carburized wrought iron. Iron tools were strong enough to work the hardest materials and quickly replaced the stone tools formerly employed.

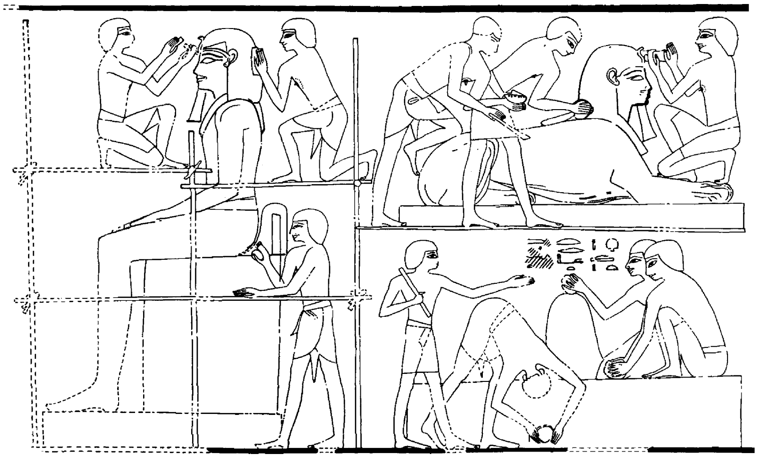
Stone Tools

"Stone mauls" were elongated, generally roughly shaped pieces of hard stone with a blunt tip and a pinched waist where a wood handle was attached (Fig. 3). In contrast to this hammer-like tool, "stone pounders" were compact, generally well rounded and often nearly spherical, pieces of hard stone that were handheld (Fig. 4). Both tools cut stone by pulverizing it. They were used to work soft as well as hard stones, but saw their greatest application with the latter.

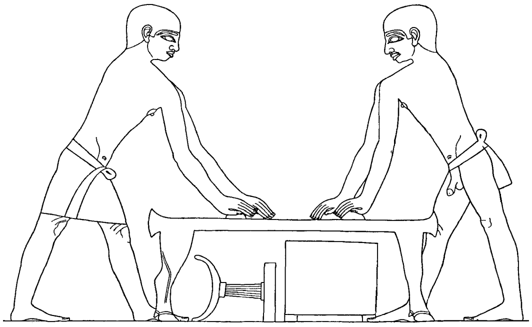
"Grinding stones" were employed for smoothing both stone and wood surfaces (Figs. 4–7). The same hard stones used for mauls and pounders were utilized



Tools Used in Ancient Egyptian Construction. Fig. 3 Stoneworkers using stone mauls (right) and possibly abrasive sand for polishing (left). Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 173).



Tools Used in Ancient Egyptian Construction. Fig. 4 Stoneworkers using grinding stones (left and upper right), a chisel struck with perhaps a small piece of wood or stone (upper left corner), stone pounders (lower right), and possibly abrasive sand for polishing (upper right – man with cup and ladle). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 60).



Tools Used in Ancient Egyptian Construction. Fig. 5 Woodworkers using grinding stones. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 174).

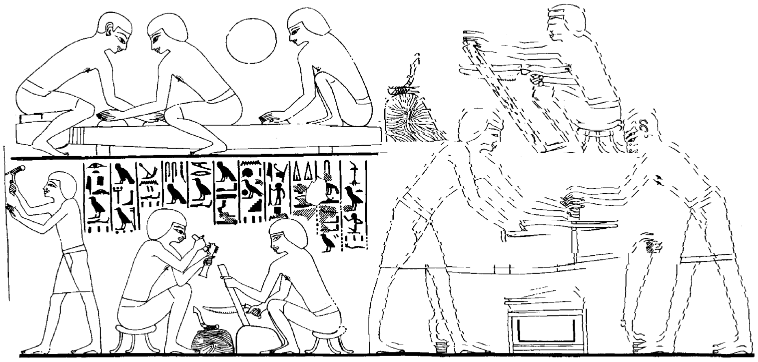
for grinders, but siliceous sandstone was especially favored for this application. Only the harder stones can take a polish, and smoothing with grinders was the first step. Producing a good, reflective polished surface required rubbing with an abrasive paste. Quartz sand was almost certainly the abrasive used, and this would have been applied with either a piece of leather or cloth (Figs. 3 and 4). Using progressively finer-grained sands would produce an increasing degree of polish.

"Hand-cranked stone drills" were used to hollow out the interiors of stone vessels, and may have had some construction applications as well (Figs. 8 and 9). The drill consisted of a wood shaft with a forked end into which was lashed either a siliceous sandstone or, more often, a chert bit. The other end of the shaft was bent to form a handle, and suspended just below this were stone weights that served to increase the downward cutting force of the bit. By cranking the handle back and forth, a worker could drill a cylindrical hole.

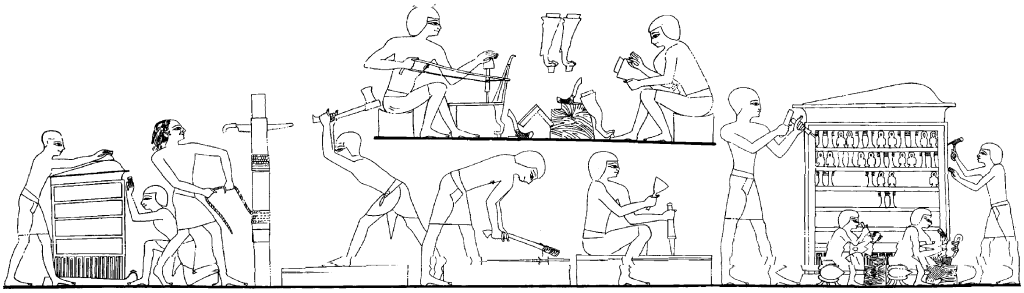
Chert is the only native Egyptian stone that can be shaped into a tool with hard, sharp points and edges. It was consequently widely utilized for a wide variety of nonconstruction applications, such as arrow and spear points, and knife and sickle blades. In woodworking, chert was used for axe and adze blades, but it is unclear whether this stone was also used in stoneworking. It has been shown experimentally that chert pick heads, adze blades and chisels can easily cut the softer stones (limestone and sandstone), and chert gravers (sharp-pointed inscribing tools) can be used to incise both soft and hard stones. Although there is no direct archaeological evidence for such applications, it seems likely that chert was employed for stoneworking tools.

Metal Tools

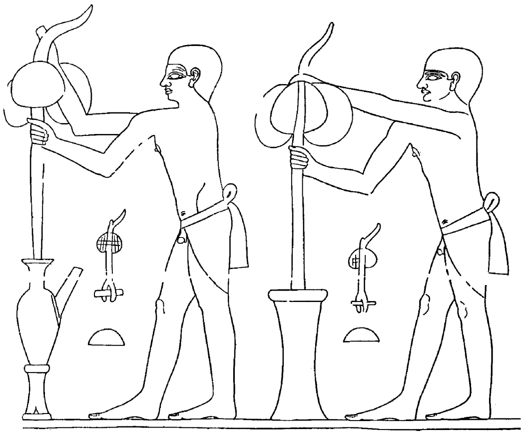
The principal metal tool used for stoneworking during the Dynastic period was the "chisel" (Figs. 1 and 4). Copper and bronze chisels were formed from stout cylindrical bars with either a pointed or flat-edged tip, and were struck with a wood mallet. Some, especially for woodworking, were fitted with a wood handle (Figs. 7 and 10). The chisels were used to dress soft stones, and to cut holes and grooves in wood. Even for such soft materials, the tips needed frequent sharpening. It was not until the advent of iron chisels (and the first metal hammers) during the Late period that the hard stones were worked with metal tools. Copper and bronze "gads" resemble chisels but were not used for cutting. They were instead hammered into existing cracks and fractures within wood or stone in order to split these materials. The woodworkers also used a



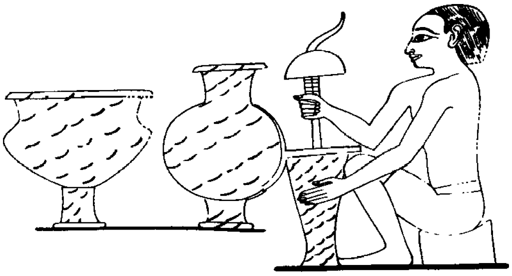
Tools Used in Ancient Egyptian Construction. Fig. 6 Woodworkers using grinding stones (upper left), an adze (far lower left), a gouge (lower left), saws (lower left and upper right), and a bow drill (lower right). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 53).



Tools Used in Ancient Egyptian Construction. Fig. 7 Woodworkers using grinding stones (far left), a saw and axes (lower center left), mallet-struck chisels and adzes (lower center right and far right), a gouge (lower right), and a bow drill (upper



Tools Used in Ancient Egyptian Construction. Fig. 8 Stoneworkers using hand-cranked drills with stone weights just below the handles. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 173).

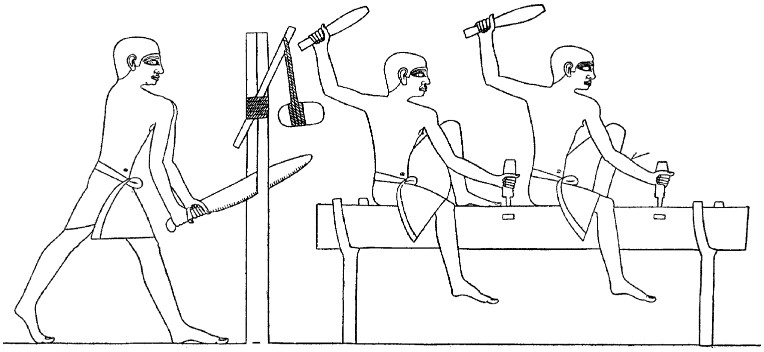


Tools Used in Ancient Egyptian Construction. Fig. 9 Stoneworker using a hand-cranked drill with a stone weight just below the handle. Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 54).

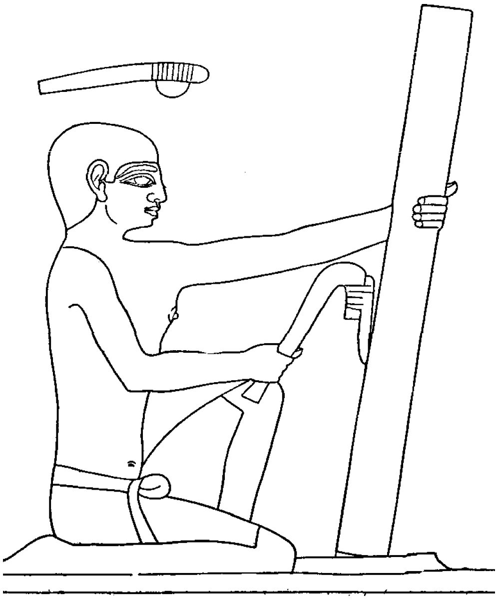
"gouge," which was a small hand-held, chisel-like tool for cutting grooves (Fig. 6).

"Adzes" are essentially flat chisels with a broad, straight cutting edge that were mounted on the end of a hooked wood handle (Figs. 2, 6, 7, 11, and 12). Blades of both metal and chert were employed. Adzes were used for trimming and smoothing soft stone surfaces, and were especially effective for stripping wood.

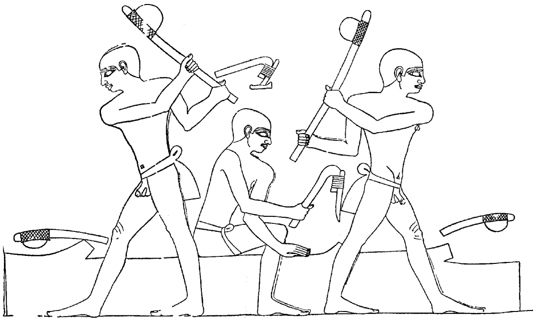
Copper and bronze "saws" were employed for cutting wood and stone (Figs. 2, 6, 7, 10, and 13). Those with a serrated blade cut both wood and soft



Tools Used in Ancient Egyptian Construction. Fig. 10 Woodworkers using a saw (left; note the stone weight keeping the saw cut open) and mallet-struck, wood-hafted chisels (right). Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 129).

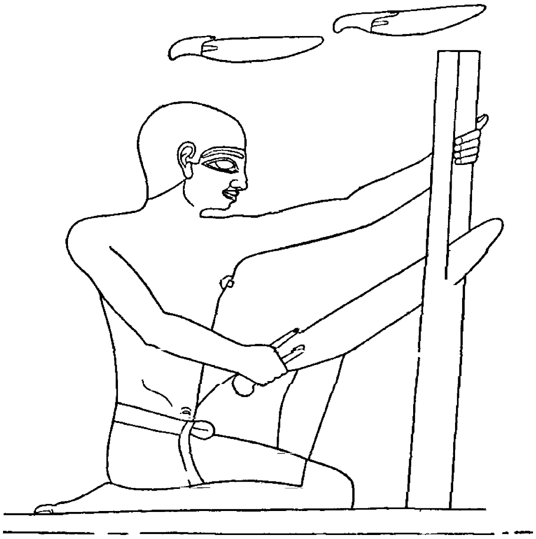


Tools Used in Ancient Egyptian Construction. Fig. 11 Woodworker using an adze. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). Note the axe at top. From Wild (1966: pl. 174).



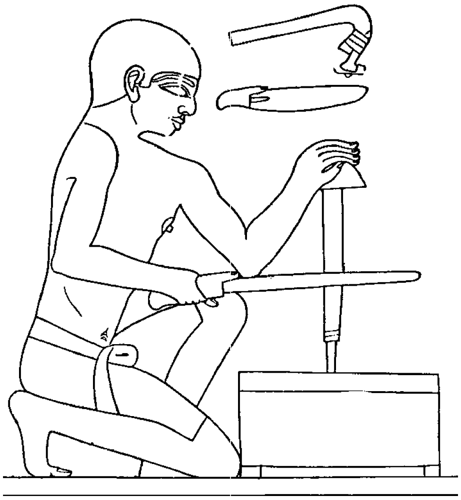
Tools Used in Ancient Egyptian Construction. Fig. 12 Woodworkers using axes (left and right) and an adze (center). Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 129).

stone, whereas saws with smooth, nonserrated blades were used to cut the hard stones. In the latter case, the cutting was not done by the metal blade itself (unlike the serrated blades used for softer materials) but rather by a quartz sand abrasive that was fed into the saw cut and over which the metal blade moved. Weights were normally attached to the ends of the longer saws of both types in order to increase the downward cutting force. Although iron saws eventually replaced those of copper and bronze, the basic designs did not change: serrated blades for soft materials, and nonserrated blades for hard stones.



Tools Used in Ancient Egyptian Construction. Fig. 13 Woodworker using a saw. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Wild (1966: pl. 174).

"Bow drills" with a metal bit ("bit drills") were used to cut holes through wood and soft stones (Figs. 6, 7, and 14). The drill consisted of a wood shaft into one end of which was fitted a solid metal bit. A bow strung with cord (similar to those wielded by archers) was used to rotate the drill shaft. This was accomplished by tightly looping the bow cord around the shaft and then moving the bow back and forth. While operating the bow with one hand, the worker used his other hand to hold onto a loosely fitting, hemispherical wood or stone cap on top of the drill shaft. In place of the solid metal bit, other bow drills were fitted with a hollow metal tube ("tube drills"). Unlike the bit drill, where the bit itself does the cutting, the tube drill used a quartz sand abrasive fed into the bottom of the hole. As with the nonserrated saw, it was the quartz sand that did the actual cutting, thus making the tube drill suitable for hard stones. As a by-product of the use of this kind of drilling, a cylindrical core was extracted from the hole. Both types of drills originally had copper or bronze fittings; later ones were made of iron. Both were also much used in woodworking to produce the holes for doweled joints and lashings.



Tools Used in Ancient Egyptian Construction.
Fig. 14 Woodworker using a bow drill. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). Note the adze and saw at top. From Wild (1966: pl. 174).

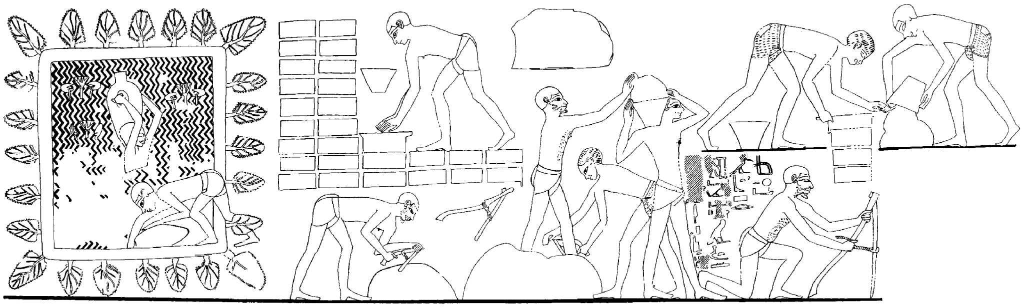
An especially important tool for woodworking was the "axe," which was used to chop and cleave wood (Figs. 7 and 12). Axes had either a subcircular or subrectangular metal blade that flared out into lugs on the dull side and were used in lashing the blade onto a wood handle.

Tools for Mud Brick Manufacturing

Mud bricks were made from a mixture of fine-grained sediment (especially clay-rich mud), sand, chopped straw or other plant chaff, and perhaps also, as in modern-day Egyptian mud bricks, animal manure (Fig. 15). Excavation of the sediment and mixing the ingredients was done with the same "hoe" used by the ancient farmers. The wood blade of this tool had a narrow extension or "tang" on one side and this was fitted into a hole cut through one end of a short wood handle, with the two parts lashed together. The mud mixture was typically packed into wood "moulds" to produce bricks of uniform size. After drying and hardening in the sun, the bricks were ready for use.

Moving Tools

The construction of stone buildings required the lateral movement and lifting of stone blocks weighing anywhere from a few tons to tens (and exceptionally hundreds) of tons. Nearly all of this work was done with ropes, levers, and sledges combined with a large measure of human muscle. The ancient Egyptians had ropes made from a variety of materials, including palm fibers, grasses, and papyrus and other reeds. Ropes up to several centimeters thick have been found and would have been strong enough for the heaviest loads. These

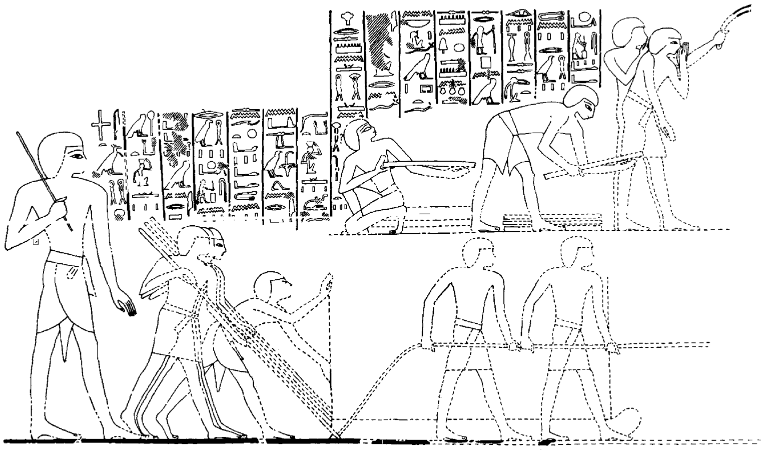


Tools Used in Ancient Egyptian Construction. Fig. 15 Workers making mud bricks: obtaining water from a pond (far left), mixing the wet mud with hoes (lower center), placing the mud in brick moulds (upper center and upper right). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 58).

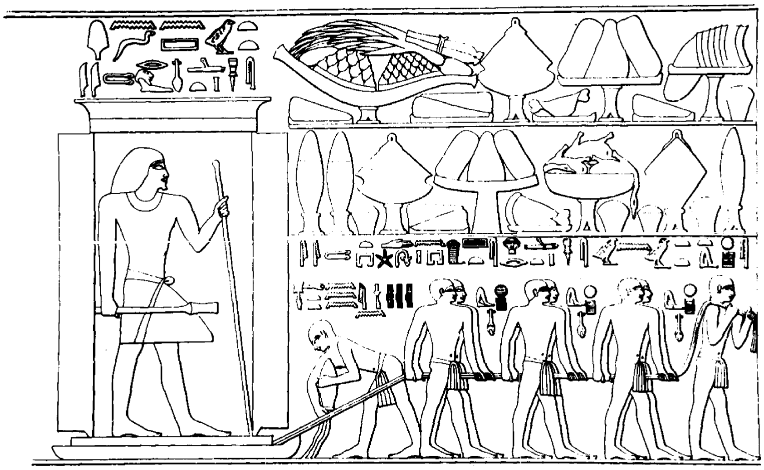
were sometimes used in conjunction with grooved "bearing blocks," which were carved from wood or stone and served as rope guides. By draping a rope around this device, the workers were able to pull from an angle.

Stout wood poles or beams were employed as "levers" for shifting stone blocks (Fig. 16). The largest were operated by teams of workers who would pull down on the elevated end with attached ropes. Stone blocks sometimes had small recesses ("lever sockets or holes") cut along their sides where the lower ends of levers could be inserted. Wood or stone "fulcrums" were placed under the lower end of these levers, and wedge-shaped pieces of wood were pushed under the levered-up edge of a block to allow deeper insertion of the lever.

"Sledges" made from wood were employed for moving heavy loads around the construction site (Figs. 16 and 17). This conveyance consisted of two parallel runners joined by a series of crossbeams. Along the sides, on top of the runners, wood stakes or other attachments would have been present to restrain the load or anchor tie-down ropes. The front ends of the runners were rounded and angled upward to allow the sledge to ride up and over irregularities in the ground. The back ends of the runners were often



Tools Used in Ancient Egyptian Construction. Fig. 16 Workers with a sledge using levers behind it (lower left), pulling on a rope (lower right), and handling sleepers (or rollers?; upper right). Redrawn from a painting in the tomb of Rekhmira (18th Dynasty). From Davies (1943: pl. 58).



Tools Used in Ancient Egyptian Construction. Fig. 17 Workers pulling a sledge with ropes while another worker pours water on the ground in front of the sledge. Note the rounded front and chamfered rear of the sledge runner. Redrawn from a relief carving in the tomb of Ti (5th Dynasty). From Epron (1939: pl. 52).

chamfered (beveled) with a cut angling downward toward the front of the sledge (as in Fig. 17), and these allowed the insertion of levers to help move the sledge forward or adjust its direction. Using attached ropes, the sledges were pulled by teams of men or, less often, draft animals.

In order to reduce ground friction, the sledges were pulled over either wetted ground or wood beams ("sleepers") laid crosswise along the sledge's path (Fig. 16). It has been suggested that the sledges were also sometimes pulled over wood "rollers," but this is unlikely as rollers would only be effective on ground that was hard, smooth, and relatively flat. Even though the Egyptians knew about the wheel from earliest Dynastic times, they had no wheeled wagons until the early New Kingdom. From this time onward, wagons may have been used for hauling stone blocks, especially the smaller ones, but sledges almost certainly remained the main conveyance for moving blocks around the construction site.

Wood "rollers" were apparently sometimes placed directly under stone blocks when these were being moved across hard, flat pavements. Another tool thought to also assist in moving stone blocks is the so-called "rocker." Made from wood, this device had two parallel, vertical sides that were joined by cross-beams as in the sledges. The tops of the sides were flat and level, and their bottoms were rounded into a half circle or ellipse. There is much speculation on how the rockers were used, but it is generally agreed that a block of stone was placed on top of the sides, and then by rocking it back and forth, the block could be "walked" across a hard surface or pivoted to assist in its placement.

Extra: Wood or Iron Wedges?

In hard stone quarries dating to the Late period and especially the subsequent Greco-Roman periods, one sees lines of wedge-shaped holes on quarry faces and extracted blocks. It is a common misconception that these holes were cut to hold wedges of wood, which when wetted would swell and so split the rock along the line of wedge holes. In actuality, however, these holes were cut to hold iron wedges, which were struck with an iron sledgehammer to split the stone. This same method of splitting stone was also used in stone construction work toward the end of the Dynastic period.

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Trephination

RUBEN G. MENDOZA

Perhaps one of the least understood surgical practices performed in ancient America concerns cranial trephination (also spelled "trepanation"), or the surgical modification of the skull. While much of the prevailing literature is largely dated, an older generation of theories tended to ascribe the practice to primitive wonderment and notions of spirit release and possession. This is despite a substantial body of technical evidence available from trephined specimens and a large and specialized body of surgical instruments and procedures documented in archaeological and contact-period historical contexts. According to medical historian Guido Majno, trephination was used as a cure for a number of ailments including skull fractures and related trauma, epileptic seizures, and insanity. In fact, many of those skulls examined to date bear evidence of blunt trauma or pathology that may provide a more direct indicator of why the practice was carried out in the first place.

While ancient Peru provides the largest body of trephined specimens available for study, and the clearest evidence of an established medical tradition in skull surgery, other important specimens have been reported from throughout the Americas. Documented examples, with evidence of osteitis, have been reported from the Mexican states of Chihuahua and Oaxaca, and archaeological sites in Lamy, New Mexico, and Accokeek, Maryland, in the United States, where trephined surgical openings are often no more than 2 cm in diameter. Reported trephined specimens from Columbia County, Georgia, archaeological zones along the Skeena River, and in the sites of Eburne and Lytton, British Columbia and Kodiak Island, Alaska, range between 3.8 and 6.0 cm in diameter. If all the putative cases of trephination reported in these examples are a reliable indication of areas in which the practice was known, then cranial trephination was quite widespread.

Majno has identified five primary techniques of trephination in specimens from both Peru and Mesoamerica. These include the most ancient method on record – the scraping-away of that bone just underlying the scalp – as well as other techniques such as grooving, boring, cutting, sawing, and rectangular intersection incision, the most predominant method employed, in which cut, sawed, or abraded grooves were used to perforate the skull in a rectangular pattern. Once the intersection incisions were connected to each other, a rectangular or octagonally shaped plate of bone remaining within the intersection was removed with a spatula-like device. Schendel (1968) notes that "the trepanning technique used in Mexico was to punch a series of small holes in the skull outlining the fracture, or the area to be removed, then to cut between those holes and lift off the depressed section of cranial bone." After this initial procedure, the exposed brain was protected with a thin plate of hardwood and cotton pads. When trephination was not deemed suitable because of the extent of skull trauma, the damaged portion of skull was encased in a protective plaster cast. There were two types of plaster cast. The first was a mixture of feathers, egg whites, and resin, and the second was prepared from a mixture of animal ash, blood, and egg whites.

Specialized tools and instruments employed by Inca physicians in the trephination of the skull included *tumi* knives crafted from alloyed and annealed, or metallurgically hardened, copper and bronze metals. The *tumi* knife consisted of a crescent-shaped blade, at the midpoint of which was attached a cylindrical metal handle or other appendage. *Tumi* knives used in trephination included razor sharp, serrated, or other sawtooth-edged crescent-shaped scalpels. Additional instruments included bronze perforators, drills, and chisels. The basic surgical instrumentation utilized in cranial trephination long predated the rise of the Inca state, whose government came to sponsor and control this specialized field of medical endeavor (Burland 1967). Cranial trephination, and both *tumi* knives and bronze perforators, are frequently depicted on the carved and painted surfaces of vessels of the Mochica civilization of the north coast of Peru (ca. AD 500).

In one collection of 273 skulls from Peru, 47 bore evidence of having been trephined between one and five times. According to Majno, the skulls studied thus far suggest that the survival rate was near 100%. Only a few cases of osteomyelitis, or bone deterioration, were documented in the cranial collection he examined. Those cases appear to have been associated primarily with the size of the original injury, and whether or not the trauma was located at the base of the skull. Apparently, patients suffering blunt trauma over the cerebral cortex or brain stem were least likely to benefit from treatment by trephination. In other recent studies, projected survival rates, based on the examination of the presence of osteitis, range from 62.5% in one study that found healing or evidence of osteitis in 250 of 400 skulls examined, to between 23.4% and 55.3% in other studies (Froeschner 1992). These latter figures are questionable in that the studies cited by Froeschner do not distinguish postmortem trephination from that performed on severely traumatized patients. Froeschner's review also fails to acknowledge the existence of even the most basic metal instruments and surgical kits documented for the practice of trephination in ancient Peru, claiming instead that "primitive tools" were the mainstay of the art of Inca trephining.

It is clear that specialized techniques and treatments contributed to the diversity and variation in surgical localities known from trephined specimens alone. In one analysis of a trephined skull collection consisting of 112 specimens (the Tello collection housed at the Peabody Museum of Harvard), 53.6% of the skulls, or 60 specimens, bore trephined areas in the frontal area of the skull (26 of which were situated in the frontal bone, 12 in the region of the bregma, and another 12 crossing over the left coronal suture); 33%, or 37 specimens, were trephined in the parietal area (18 of which bore surgical openings over the left parietal, while 15 crossed the sagital suture), and 13.4%, or 15 specimens, were trephined over the occipital area (with seven in the region of the lambda, and four in the occipital bone). Most trephined specimens from the Harvard collection bear surgical openings within the frontal areas of the cranium, and again, trephined openings are most highly correlated with blunt trauma and other pathologies. The incidence of epileptic seizures among Inca era peoples was documented by both European-contact chroniclers and contact-era Inca scribes. This fact may provide directions for future inquiry into the origins of specific types of trephination among Inca and related peoples.

Based on a worldwide survey of ancient skull surgery, Majno has concluded that the Inca were the "Masters of the Art of Trepanning." He also noted that the survival rate for patients in Inca times was better than for such rates in modern times. He says that modern survival rates are the inverse of what they had been in earlier Inca times, and concludes that modern humans complicated the task of skull surgery by introducing new sources of infection and disease. In turn, modern physicians were trained to perpetuate otherwise antiquated traditions of skull surgery based on flawed nineteenth century assumptions and beliefs.

European medical belief systems regarding infection, surgical procedure, anesthetics, and basic hygiene necessitated a constantly expanding and contracting repertoire of experimental procedures which further complicated survival rates. As a result, the fledgling early twentieth century version of modern skull surgery suffered many casualties.

See also: ►Medicine in Mesoamerica; ►Surgery in India

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Tribology

LU JING-YAN

Tribology, the study of the phenomena and mechanisms of friction, lubrication, and wear of surfaces in relative motion, can be traced back to remote antiquity in China, where it developed significantly.

Sliding bearings were discovered in ancient mechanisms, especially in carts which operated at high speeds and carried great loads. In order to reduce friction and damage, Chinese mechanics lubricated bearings on their carts. This was recorded in the earliest poetry collection entitled *Bei Fen Quan Shu* (The Bei Wind and Spring Water) as follows:

The grease used is sufficient to lubricate the axle shaft.
On the shaft end, we carefully check the pin bolt.
Quickly, send me home driving the cart.
Quickly, send me back to my Wei country town.

It proves that before the book *Shi Jing* (Poems and Odes) appeared – before 1100–600 BCE – lubricant was widely applied in China. Owing to their rhythmic quality, the verses were repeatedly quoted and talked about, and often appeared in later books as well.

By the time of the Chun Qui (Spring–Autumn) period (500 BCE) in the Lu and Qi states, there was a group of special officers called *Jinche*, whose duty was to check the pin bolts on the shaft ends. They were probably the earliest tribology supervisors. This demonstrates that the ancient Chinese already knew well that the better the lubrication, the faster and easier ran the cart.

Early lubricant was called *zhi* or *gao*. According to research on ancient characters, *zhi* was the fat of horned animals, and that of hornless animals was called *gao*. The lubricant used might be sheep oil, which was easier to get. Since *zhi* or *gao* is in a solid state at normal temperature, it had to be heated and melted before it was used. In 300 BCE petroleum began to be used.

Metal bushes appeared in China quite early. There were relevant records about their use in *Wuzi Yebing* (Wuzi casting), which shows that they appeared not later than 400 BCE. The metal bush was made of two layers: outside and inside. The outer one was called *gong*, which turned together with the wheel, and the inside one was *jian*, which turned together with the shaft. Between them a kind of lubricant was provided, and the cart ran quickly and easily. In addition to carts, the metal bushes were applied in other mechanisms of antiquity, and they appeared in a variety of forms. In the Han Dynasty, they were already used quite widely. This is illustrated by the discovery of hundreds of mold sets of metal bushes in county Wen in Henan province.

Most of them were still undamaged. They reflect the level of manufacturing as well as the scale of their production and application in the Han Dynasty.

The ancients took other measures to reduce friction and damage. Most mechanisms were made of wood. In the *Kao Gongji* (The Artificer's Record), three principles of wood selection were listed (1) the wood must be smooth, without joints; (2) it must be tough and wear-resistant; and (3) it must be thick enough and easy to revolve. In the sixteenth century a book entitled *Tian Gong Kaiwu* (Exploitation of the Works of Nature) was written, in which a further summary on the basis of experience was made. It analyzed the advantages and shortcomings of various woods, and provided an example: if wood works for too long, it gives out heat. In the field of structural design, the *Kao Gongji* and other books analyzed the relationship between the axis path and the length of the shaft, and pointed out that when the cart and load were different, the interior axis of the wheel must keep a fixed proportion to the length of the shaft.

There was one other achievement of note in this field. In the Yuan Dynasty (thirteenth century) a ball bearing, which was circle-formed and consisted of four balls, was successfully applied to an astronomical instrument made by Guo Shoujing.

Trigonometry in Indian Mathematics

MICHIO YANO

Trigonometry offers one of the most remarkable examples of transmission of the exact sciences in antiquity and the Middle Ages. Originating in Greece, it was transmitted to India and, with several modifications, passed into the Islamic world. After further development it found its way to medieval Europe.

The very term "sine" illustrates the process of transmission. The Greek word for "chord" (εὐθεῖα, literally "a straight line [subtending an arc]") was translated into Sanskrit as *jīva* or *jyā* ("string of a bow") from the similarity of its appearance. The former word was phonetically translated into Arabic as *jyb*, which was vocalized as *jayb* (meaning "fold" in Arabic), and this was again translated into Latin as *sinus*, an equivalent to the English sine.

It was by tracking back along this stream of transmission that the first chord table ascribed to Hipparchus (fl. 150 BCE) was recovered by Toomer (1973) from an Indian sine table (compare Tables 1 and 2). Toomer showed that some numerical values ascribed to Hipparchus in the *Almagest* of Ptolemy (fl. AD 150) could be explained by hypothesizing the use of this reconstructed table.

Trigonometry in Indian Mathematics. Table 1 Hipparchus' chord table reconstructed

Number	α	R crd α
1	7; 30	450
2	15	897
3	22; 30	1,341
4	30	1,779
5	37; 30	2,210
6	45	2,631
7	52; 30	3,041
8	60	3,438
9	67; 30	3,820
10	75	4,185
11	82; 30	4,533
12	90	4,862
13	97; 30	5,169
14	105	5,455
15	112; 30	5,717
16	120	5,954
17	127; 30	6,166
18	135	6,352
19	142; 30	6,510
20	150	6,641
21	157; 30	6,743
22	165	6,817
23	172; 30	6,861
24	180	6,875

According to this reconstruction, Hipparchus used 6,875′ as the length of the diameter (1) of the base circle, in other words, as the greatest chord subtending the half circle$(= R\,\mathrm{crd}\,180^{\circ} = 6{,}875)$. This number is the result of rounding after dividing 21,600′ (360°) by the value of $\pi = 3; 8, 30$. (In this article we follow the convention: integer and fraction are separated by a semicolon, the former is in decimal form and the latter is in sexagesimal form with commas to separate the places.) In India 3,438′, namely, the rounded half of D, was used as the length of the radius (R), which is the largest "half chord" (*jyārdha* or *ardhajyā*).

Thus the relation between the Greek chord and the Indian sine can be expressed as:

$$AB = 2AH, \quad R\,\mathrm{crd}\,2\alpha = 2\mathrm{R}\,\sin\,\alpha. \qquad (1)$$

Plane trigonometry was the essential tool for mathematical astronomy in India. All the astronomical texts in Sanskrit either give a kind of sine table or presuppose one. On the other hand, trigonometry was studied only as a part of astronomy and it was never an independent subject of mathematics. Furthermore since they were not aware of spherical trigonometry, Indian astronomers developed the method called *chedyaka* in which the sphere was projected on to a plane.

Trigonometry in Indian Mathematics. Table 2 Indian sine table with $R = 3{,}438$

Number	α	$R \sin \alpha$	Δ
1	3; 45	225	225
2	7; 30	449	224
3	11; 15	671	222
4	15	890	219
5	18; 45	1,105	215
6	22; 30	1,315	210
7	26; 15	1,520	205
8	30	1,719	199
9	33; 45	1,910	191
10	37; 30	2,093	183
11	41; 15	2,267	174
12	45	2,431	164
13	48; 45	2,585	154
14	52; 30	2,728	143
15	56; 15	2,859	131
16	60	2,978	119
17	63; 45	3,084	106
18	67; 30	3,177	93
19	71; 15	3,256	79
20	75	3,321	65
21	78; 45	3,372	51
22	82; 30	3,409	37
23	86; 15	3,431	22
24	90	3,438	7

Sine Table with $R = 3{,}438$

The earliest Indian sine table with $R = 3{,}438$ is found in Āryabhaṭa's book on astronomy, *Āryabhaṭīya* (AD 499). It should be remembered that "table" here does not mean that the numbers are actually arranged in a tabular form, i.e., in lines and columns. As is usually the case with Sanskrit scientific texts, all the numbers are expressed verbally in verse. For brevity's sake, Āryabhaṭa gives only the tabular differences (Δ, the fourth column of Table 2). This is the standard sine table in ancient India. Exactly the same table is found in the *jiuzhili*, a Chinese text on the Indian calendar written in AD 718 by an astronomer of Indian descent, but it did not have any influence on Chinese mathematics.

The values of sines were geometrically derived from $R \sin 90°$ (=R) and $R \sin 30°$ (=R) by two formulas:

$$R \sin(90^\circ - \alpha) = \sqrt{R^2 - (R \sin \alpha)^2}, \qquad (2)$$

$$R \sin\frac{\alpha}{2} = \sqrt{\left\{\frac{R - R\sin(90^\circ - \alpha)}{2}\right\}^2 + \left(\frac{R \sin \alpha}{2}\right)^2}. \qquad (3)$$

It is worth noting here that the first tabular sine was equated with the arc ($3;45° = 225'$) which it subtends. This means that, when α' is small enough, the approximation$\sin \alpha' \approx \alpha'$ can be applied.

What is more remarkable in Āryabhaṭa is that he gives an alternative method for computing tabular differences by means of the formula:

$$\Delta_{n+1} = \Delta_n - (\Delta_1 - \Delta_2)\frac{J_n}{J_1},$$

where $J_n = R \sin n(3;45^\circ)$. The formula, after several centuries of misunderstanding, was correctly interpreted by a South Indian astronomer Nīlakaṇṭha (born in 1444), one of the most distinguished scholars belonging to the Mādhava school (see below). When suitable values of $(\Delta_1 - \Delta_2)$ and J_1 are used, this formula produces very good values for the rest of R sins. It seems that Āryabhaṭa's sine values were computed by this second method rather than by the geometrical method. This means that the table with $R = 3{,}438$ is not a mere copy of the Hipparchan table, if ever existed.

Sine Table with $R = 120$

There is another kind of Indian sine table which uses $R = 120$. The table is found in the *Pañcasiddhāntikā* of Varāhamihira, a younger contemporary of Āryabhaṭa. This table is closely related to the Greek chord table with $R = 60$ which is offered in Ptolemy's *Almagest*. Because of the relation (1) given above, all the numerical values in the chord table with $R = 60$ can be transferred directly to the sine table with $R = 120$. Table 3 compares the first four and the last four values in the *Pañcasiddhāntikā* with Ptolemy's corresponding ones. The fractional parts after the semicolon in both tables are expressed sexagesimally. It seems that Varāhamihira's values were the results of rounding the numbers in the second fractional place of a chord table similar to that of Ptolemy.

In these earlier Indian sine tables, only the 24 values in the first quadrant are given, with the interval of $3°45'$. Although Indians knew and used cosines (*koṭijyā*), they had no need of tabulating them because they knew that cosines could be derived from sines by the relation (2) above. On the other hand they were interested in the versed sine (*śara* in Sanskrit, meaning "arrow" or *utkramajyā*, "sine of the reversed order," CH in Fig. 1) which is defined as:

$$R \operatorname{vers} \alpha' = R - R \sin(90^\circ - \alpha).$$

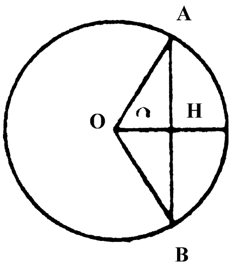
Using this relation, Brahmagupta (seventh century) simplified some formulas. For instance, formula (3) was rewritten as:

$$R \sin\frac{\alpha}{2} = \sqrt{\frac{D \times R \operatorname{vers} \alpha}{4}}. \qquad (3')$$

A table of versed sines can be easily obtained by adding Δs in Table 2 successively from the bottom upward (namely, in the "reversed order").

Trigonometry in Indian Mathematics. Table 3 Comparison of the first four and last four values in the *Pañcasiddhāntikā* with those of Ptolemy

Number	**α (°)**	**Varāhamihira with R = 120**	**Ptolemy with R = 60**
		R sin α	**R crd 2α**
1	3; 45	7; 51	7; 50, 54
2	7; 30	15; 40	15; 39, 47
3	11; 15	23; 25	23; 24, 39
4	15	31; 4	31; 3, 30
…	…	…	…
21	78; 45	117; 42	117; 41, 40
22	82; 30	118; 59	118; 58, 25
23	86; 15	119; 44	119; 44, 36
24	90	120	120



Trigonometry in Indian Mathematics. Fig. 1 Sine of the reversed order.

Brahmagupta computed anew 24 sines with R = 3,270 in the *Brāhmasphuṭasiddhānta*. Elsewhere in this book and in the *Khaṇḍakhādyaka*, he offers a sine table with R = 150 and with the interval of 15°. This small table generates remarkably correct sine values when his ingenious method of second order interpolation is applied.

Bhāskara II

An improved version of the traditional sine table was prepared by Bhāskara II (b. 1114). In the chapter "Derivation of Sines" (*Jyotpatti*) of his *Siddhāntaśiromaṇi* he introduces two new values:

$$R\ \sin\ 36^{\circ} = \sqrt{\frac{5-\sqrt{5}}{8}}R,$$

$$R\ \sin\ 18^{\circ} = \sqrt{\frac{\sqrt{5}-1}{4}}R.$$

With these two values and formulas (2) and (3) above, he obtains R sin 3n° (where n = 1, 2, 3,…, 30). Further he combines them with the approximate value

$$R\ \sin\ 1^{\circ} \approx 60'$$

using the new formula

$$R\sin(\alpha \pm \beta) = \frac{R\sin\alpha R\cos\beta \pm R\cos\alpha R\sin\beta}{R}, \quad (4)$$

which is equivalent to the modern formula:

$$\sin(\alpha \pm \beta) = \sin\ \alpha\ \cos\ \beta \pm \cos\ \alpha\ \sin\ \beta.$$

Thus he could obtain sines for all the integer degrees of a quadrant. Formula (4) was unknown to Indians before Bhāskara II, while a chord version of the same formula was known to Ptolemy.

Trigonometry underwent a remarkable development in the early fifteenth century on the western coast of South India (the modern state of Kerala). The person who initiated this development was Mādhava (fl. ca. 1380/1420) of Saṅgamagrāma (near modern Cochin). His important works on astronomy and mathematics are now lost, but we know his achievements from the books of his successors. A sine table ascribed to him is quoted in Nīlakaṇṭha's commentary on the *Āryabhaṭīya* (Table 4).

A couple of verses, which are often quoted by the students of the Mādhava school and which are ascribed to Mādhava himself by Nīlakaṇṭha, give the method of computing sines. The method can be expressed as

$$R\ \sin\ \theta = \theta - \frac{\theta^3}{3!R^2} + \frac{\theta^5}{5!R^4} - \frac{\theta^7}{7!R^6} + \frac{\theta^9}{9!R^8} - \cdots$$

with R = 1 this is equivalent to Newton's

$$\sin\ \theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \frac{\theta^9}{9!} - \cdots.$$

Similar power series for cosine and versed sine are ascribed to Mādhava.

Trigonometry in Indian Mathematics. Table 4 Mādhava's sine table

Number	α (°)	$R \sin \alpha$
1	3; 45	0224; 50, 22
2	7; 30	0448; 42, 58
3	11; 15	0670; 40, 16
4	15	0889; 45, 15
5	18; 45	1,105; 01, 39
6	22; 30	1,315; 34, 07
7	26; 15	1,520; 28, 35
8	30	1,718; 52, 24
9	33; 45	1,909; 54, 35
10	37; 30	2,092; 46, 03
11	41; 15	2,266; 39, 50
12	45	2,430; 51, 15
13	48; 45	2,548; 38, 06
14	52; 30	2,727; 20, 52
15	56; 15	2,858; 22, 55
16	60	2,977; 10, 34
17	63; 45	3,038; 13, 17
18	67; 30	3,176; 03, 50
19	71; 15	3,255; 18, 22
20	75	3,320; 36, 30
21	78; 45	3,321; 41, 29
22	82; 30	3,408; 20, 11
23	86; 15	3,430; 23, 11
24	90	3,437; 44, 48

See also: ►*Almagest*, ►Sexagesimal System, ►Āryabhaṭa, ►Mādhava, ►Varāhamihira, ►Brahmagupta, ►Śrīpati, ►Nīlakaṇṭha

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Trigonometry in Islamic Mathematics

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Trigonometry is the connecting link between mathematics and astronomy, between the way calendars are calculated, the gnomon, and the sundial. In the Islamic world, the calculation of spherical triangles was necessary to carry out ritual customs. The *qibla*, the direction to Mecca, was indicated next to the hour lines on all public sundials.

The first trigonometric problems appeared in the field of spherical astronomy. Around the year 773 one of the Indian *siddhāntas* (astronomy books) was made known in Baghdad. The Indian astronomers Varāhamihira (fifth century) and Brahmagupta (sixth century) solved different problems in spherical astronomy by means of rules equivalent to a general sine theorem for a spherical triangle ABC with sides a, b, c and angles A, B, C (where angle A is opposite to side a, etc.), namely $(\sin A/\sin a) = (\sin B/\sin b) = (\sin C/\sin c)$ and to the cosine theorem for the same triangle $\cos a = \cos b \cos c + \sin b \sin c \cos A$.

In the ninth century Ptolemy's *Almagest* and Menelaus' *Spherics* were also translated, and commentaries were written to these works. Many trigonometrical problems were solved in Ptolemy's *Almagest*, in which Menelaus' theorem on the spherical complete quadrilateral was used. The cases of this theorem used by Ptolemy are equivalent to the sine and tangent theorems for a right-angled spherical triangle. The *Almagest*, the *Spherics*, and the Indian *siddhāntas* formed the basis on which Arab mathematicians built their trigonometry.

The ancient Greek astronomers only used one trigonometric function, the chord of an arc. The "theorem of Ptolemy," which is equivalent to the formula for the sine of the sum of the angles, forms, together with the formula for the chord of the half arc, the basis for the chord table in the *Almagest*. The Indian people replaced the chord with the sine, introduced the cosine and the versed sine, and compiled a small table of sine values. The Arabic mathematicians progressively made trigonometry into a science independent of its (astronomical) context.

Applications of trigonometry analogous to those in the Indian *siddhāntas* are found in the astronomical works of al-Khwārizmī. An analogous geometric construction for finding the azimuth according to the rule formulated in al-Khwārizmī's third treatise was provided by al-Māhānī (ca. 825–888) in his *Treatise on the Determination of the Azimuth at Any Time and in Any Place*. The rules equivalent to the spherical sine and cosine theorems were also used by Thābit ibn Qurra in his *Book on Horary Instruments Called Sundials*. With Ḥabash the applications of the tangent and cotangent functions went beyond the usual applications in the theory of sundials. The introduction of the tangent and cotangent and their application in astronomy was a novelty. The names *zill* (shadow) and *zill maᶜqus* (reversed shadow) apparently are translations from Sanskrit. In the case of a vertical gnomon, al-Ḥabas expressed the cosecant as the "diameter of the shadow" for a given height of the sun, i.e., as a hypotenuse. He computed a table for the cosecant with steps of 1°.

For a long time, the chord was used along with the sine. A theory of these magnitudes is found in the work of al-Battānī (ca. 858–929). In his astronomical work *Islaḥ al-Majisṭī* (The Perfection of the Almagest), he systematically employed the trigonometric functions sine and versed sine with arguments between 0° and 180°. Since the cosine is defined as the sine of the complement of the angle, and since no negative numbers are used, the versed sine is defined in the second quadrant as a sum of two quantities. The elements of trigonometry are set forth in an even more systematic way in the *Kitāb al-Kāmil* (Perfect Book) of Abū'l-Wafāʾ (940–997/998). He defined several trigonometric functions in the circle with radius 1. The trigonometrical tangent function is defined as a line on a tangent to the circle.

The proof of the general spherical sine theorem was given by Abū'l-Wafāʾ in his *al-Majisṭī* (Almagest), by his pupil Abū Naṣr ibn ʿIrāq (d. 1036) in the *Risāla fī maʿrifa al-qisī al-falakiyya* (Treatise on the Determination of Celestial Arcs), and by al-Khujandī (d. ca. 1000) in the *Kitāb fī al-sāʿāt al-māḍiyya fī al-layl* (Book on Past Hours in the Night). The history of the discovery of this theorem was described by al-Bīrūnī, the pupil of Ibn ʿIrāq and al-Khujandī, in the *Kitāb maqālīd ʿilm al-hay'a* (Book on the Keys of Astronomy).

The use of trigonometry was expanded through al-Bīrūnī (973–1048). He is the author of the *Masʿūdic Canon*, which is a summary of the results from the works of many predecessors and of personal observations and calculations. It comprises 11 books. Book 3 is dedicated to trigonometry. It has calculations equivalent to the formulas for the sine of the sum of two angles, the sine of the differences between two angles, and the sine of the double angle. It also includes the solution of cubic equations and the division of angles into three parts, and the sine rule of plane trigonometry: $(\sin A/a) = (\sin B/b) = (\sin C/c)$. (The plane cosine theorem $a^2 = b^2 + c^2 - 2bc\cos A$ is equivalent to two of Euclid's theorems.)

Another important scholar in the area of trigonometry was Naṣīr al-Dīn al-Ṭūsī (1201–1274). His principal work was *Kitāb al-shakl al-qaṭṭāʿ* (Book on the Secant Figure, also known as Treatise on the Complete Quadrilateral). It was written in Persian and translated by the author into Arabic in 1260, possibly for the needs of the observatory of Maragha. In five books, it contains a full system of trigonometrical formulas for plane and spherical triangles. If any three elements of such a triangle are given, the other three elements can be found by the theory explained in this work, which also contains the notion of the polar triangle $A'B'C'$ of a spherical triangle $ABC(A' = 180° - a,\ B' = 180° - b,\ C' = 180° - c)$. This work played an important role in the development of mathematics in Europe.

See also: ►*Qibla*, ►Varāhamihira, ►Brahmagupta, ►al-Khwārizmī, ►al-Māhānī, ►Thābit ibn Qurra, ►al-Battāni, ►Abū'l-Wafāʾ, ►al-Khujandī, ►al-Bīrūnī, ►Naṣīr al-Dīn al-Ṭūsī

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