HISTORY OF TECHNOLOGY

Volume 1

Leon McDaniel

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Chapter 1

An Overview

The history of technology is the history of the invention of tools and techniques and is one of the categories of world history. Technology can refer to methods ranging from as simple as stone tools to the complex genetic engineering and information technology that has emerged since the 1980s. The term technology comes from the Greek word techne, meaning art and craft, and the word logos, meaning word and speech. It was first used to describe applied arts, but it is now used to describe advancements and changes which affect the environment around us.

New knowledge has enabled people to create new things, and conversely, many scientific endeavors are made possible by technologies which assist humans in traveling to places they could not previously reach, and by scientific instruments by which we study nature in more detail than our natural senses allow.

Since much of technology is applied science, technical history is connected to the history of science. Since technology uses resources, technical history is tightly connected to economic history. From those resources, technology produces other resources, including *technological artifacts* used in everyday life. Technological change affects, and is affected by, a society's cultural traditions. It is a force for economic growth and a means to develop and project economic, political, military power and wealth.

Measuring technological progress

Many sociologists and anthropologists have created social theories dealing with social and cultural evolution. Some, like Lewis H. Morgan, Leslie White, and Gerhard Lenski have declared technological progress to be the primary factor driving the development of human civilization. Morgan's concept of three major stages of social evolution (savagery, barbarism, and civilization) can be divided by technological milestones, such as fire. White argued the measure by which to judge the evolution of culture was energy.

For White, "the primary function of culture" is to "harness and control energy." White differentiates between five stages of human development: In the first, people use the energy of their own muscles. In the second, they use the energy of domesticated animals. In the third, they use the energy of plants (agricultural revolution). In the fourth, they learn to use the energy of natural resources: coal, oil, gas. In the fifth, they harness nuclear energy. White introduced a formula P=E/T, where E is a measure of energy consumed, and T is the measure of the efficiency of technical factors using the energy. In his own words, "culture evolves as the amount of energy harnessed per capita per year is increased, or as the efficiency of the instrumental means of putting the energy to work is increased". Nikolai Kardashev extrapolated his theory, creating the Kardashev scale, which categorizes the energy use of advanced civilizations.

Lenski's approach focuses on information. The more information and knowledge (especially allowing the shaping of natural environment) a given society has, the more advanced it is. He identifies four stages of human development, based on advances in the history of communication. In the first stage, information is passed by genes. In the second, when humans gain sentience, they can learn and pass information through experience.

In the third, the humans start using signs and develop logic. In the fourth, they can create symbols, develop language and writing. Advancements in communications technology translate into advancements in the economic system and political system, distribution of wealth, social inequality and other spheres of social life. He also differentiates societies based on their level of technology, communication, and economy:

- hunter-gatherer,
- simple agricultural,
- advanced agricultural,
- industrial,
- special (such as fishing societies).

In economics, productivity is a measure of technological progress. Productivity increases when fewer inputs (classically labor and capital but some measures include energy and materials) are used in the production of a unit of output. Another indicator of technological progress is the development of new products and services, which is necessary to offset unemployment that would otherwise result as labor inputs are reduced.

In developed countries productivity growth has been slowing since the late 1970s; however, productivity growth was higher in some economic sectors, such as manufacturing. For example, employment in manufacturing in the United States declined from over 30% in the 1940s to just over 10% 70 years later. Similar changes occurred in other developed countries. This stage is referred to as *post-industrial*.

In the late 1970s sociologists and anthropologists like Alvin Toffler (author of *Future Shock*), Daniel Bell and John Naisbitt have approached the theories of post-industrial societies, arguing that the current era of industrial society is coming to an end, and services and information are becoming more important than industry and goods. Some extreme visions of the post-industrial society, especially in fiction, are strikingly similar to the visions of near and post-Singularity societies.

By period and geography

The following is a summary of the history of technology by time period and geography:

- Olduvai stone technology (Oldowan) 2.5 million years ago (scrapers; to butcher dead animals)
- Huts, 2 million years ago.
- Acheulean stone technology 1.6 million years ago (hand axe)
- Fire creation and manipulation, used since the Paleolithic, possibly by Homo erectus as early as 1.5 Million years ago
- Boats, 900,000 years ago.
- Cooking, 500,000 years ago.
- Javelins, 400,000 years ago.
- (Homo sapiens sapiens – modern human anatomy arises, around 200,000 years ago.)
- Glue, 200,000 years ago.

- Clothing possibly 170,000 years ago.
- Stone tools, used by Homo floresiensis, possibly 100,000 years ago.
- Harpoons, 90,000 years ago.
- Bow and arrows, 70,000–60,000 years ago.
- Sewing needles, 60,000 - 50,000 BC
- Flutes, 43,000 years ago.
- Fishing nets, 43,000 years ago.
- Ropes, 40,000 years ago.
- Ceramics c. 25,000 BC
- Fishing hooks, C. 23,000 years ago.
- Domestication of animals, c. 15,000 BC
- Sling (weapon) c. 9th millennium BC
- Microliths c. 9th millennium BC
- Brick used for construction in the Middle East c. 6000 BC
- Agriculture and Plough c. 4000 BC
- Wheel c. 4000 BC
- Gnomon c. 4000 BC
- Writing systems c. 3500 BC
- Copper c. 3200 BC
- Bronze c. 2500 BC
- Salt c. 2500 BC
- Chariot c. 2000 BC
- Iron c. 1500 BC
- Sundial c. 800 BC
- Glass ca. 500 BC
- Catapult c. 400 BC
- Cast iron c. 400 BC
- Horseshoe c. 300 BC
- Stirrup first few centuries AD

Prehistory

Stone Age

During most of the Paleolithic – the bulk of the Stone Age – all humans had a lifestyle which involved limited tools and few permanent settlements. The first major technologies were tied to survival, hunting, and food preparation. Stone tools and weapons, fire, and clothing were technological developments of major importance during this period.

Human ancestors have been using stone and other tools since long before the emergence of *Homo sapiens* approximately 200,000 years ago. The earliest methods of stone tool making, known as the Oldowan "industry", date back to at least 2.3 million years ago, with the earliest direct evidence of tool usage found in Ethiopia within the Great Rift Valley, dating back to 2.5 million years ago. This era of stone tool use is called the *Paleolithic*, or "Old stone age", and spans all of human history up to the development of agriculture approximately 12,000 years ago.

To make a stone tool, a "core" of hard stone with specific flaking properties (such as flint) was struck with a hammerstone. This flaking produced sharp edges which could be used as tools, primarily in the form of choppers or scrapers. These tools greatly aided the early humans in their hunter-gatherer lifestyle to perform a variety of tasks including butchering carcasses (and breaking bones to get at the marrow); chopping wood; cracking open nuts; skinning an animal for its hide, and even forming other tools out of softer materials such as bone and wood.

The earliest stone tools were irrelevant, being little more than a fractured rock. In the Acheulian era, beginning approximately 1.65 million years ago, methods of working these stones into specific shapes, such as hand axes emerged. This early Stone Age is described as the Lower Paleolithic.

The Middle Paleolithic, approximately 300,000 years ago, saw the introduction of the prepared-core technique, where multiple blades could be rapidly formed from a single core stone. The Upper Paleolithic, beginning approximately 40,000 years ago, saw the introduction of pressure flaking, where a wood, bone, or antler punch could be used to shape a stone very finely.

The end of the last Ice Age about 10,000 years ago is taken as the end point of the Upper Paleolithic and the beginning of the Epipaleolithic / Mesolithic. The Mesolithic technology included the use of microliths as composite stone tools, along with wood, bone, and antler tools.

The later Stone Age, during which the rudiments of agricultural technology were developed, is called the Neolithic period. During this period, polished stone tools were made from a variety of hard rocks such as flint, jade, jadeite, and greenstone, largely by working exposures as quarries, but later the valuable rocks were pursued by tunneling underground, the first steps in mining technology. The polished axes were used for forest clearance and the establishment of crop farming and were so effective as to remain in use when bronze and iron appeared. These stone axes were used alongside a continued use of stone tools such as a range of projectiles, knives, and scrapers, as well as tools, made organic materials such as wood, bone, and antler. Stone Age cultures developed music and engaged in organized warfare. Stone Age humans developed ocean-worthy outrigger canoe technology, leading to migration across the Malay archipelago, across the Indian Ocean to Madagascar and also across the Pacific Ocean, which required knowledge of the ocean currents, weather patterns, sailing, and celestial navigation.

Although Paleolithic cultures left no written records, the shift from nomadic life to settlement and agriculture can be inferred from a range of archaeological evidence. Such evidence includes ancient tools, cave paintings, and other prehistoric art, such as the Venus of Willendorf. Human remains also provide direct evidence, both through the examination of bones, and the study of mummies. Scientists and historians have been able to form significant inferences about the lifestyle and culture of various prehistoric peoples, and especially their technology.

Ancient

Copper and bronze Ages

Metallic copper occurs on the surface of weathered copper ore deposits and copper was used before copper smelting was known. Copper smelting is believed to have originated when the technology of pottery kilns allowed sufficiently high temperatures. The concentration of various elements such as arsenic increase with depth in copper ore deposits and smelting of these ores yields arsenical bronze, which can be sufficiently work hardened to be suitable for making tools. Bronze is an alloy of copper with tin; the latter being found in relatively few deposits globally caused a long time to elapse before true tin bronze became widespread. (See: Tin sources and trade in ancient times) Bronze was a major advance over stone as a material for making tools, both because of its mechanical properties like strength and ductility and because it could be cast in molds to make intricately shaped objects.

Bronze significantly advanced shipbuilding technology with better tools and bronze nails. Bronze nails replaced the old method of attaching boards of the hull with cord woven through drilled holes. Better ships enabled long-distance trade and the advance of civilization.

This technological trend apparently began in the Fertile Crescent and spread outward over time. These developments were not, and still are not, universal. The three-age system does not accurately describe the technology history of groups outside of Eurasia, and does not apply at all in the case of some isolated populations, such as the Spinifex People, the Sentinelese, and various Amazonian tribes, which still make use of Stone Age technology, and have not developed agricultural or metal technology.

Iron Age

Before iron smelting was developed the only iron was obtained from meteorites and is usually identified by having nickel content. Meteoric iron was rare and valuable, but was sometimes used to make tools and other implements, such as fish hooks.

The **Iron Age** involved the adoption of iron smelting technology. It generally replaced bronze and made it possible to produce tools which were stronger, lighter and cheaper to make than bronze equivalents. The raw materials to make iron, such as ore and limestone, are far more abundant than copper and especially tin ores. Consequently, iron was produced in many areas.

It was not possible to mass manufacture steel or pure iron because of the high temperatures required. Furnaces could reach melting temperature but the crucibles and molds needed for melting and casting had not been developed. Steel could be produced by forging bloomery iron to reduce the carbon content in a somewhat controllable way, but steel produced by this method was not homogeneous.

In many Eurasian cultures, the Iron Age was the last major step before the development of written language, though again this was not universally the case.

In Europe, large hill forts were built either as a refuge in time of war or sometimes as permanent settlements. In some cases, existing forts from the Bronze Age were expanded and enlarged. The pace of land clearance using the more effective iron axes increased, providing more farmland to support the growing population.

Mesopotamia

Mesopotamia (modern Iraq) and its peoples (Sumerians, Akkadians, Assyrians and Babylonians) lived in cities from c. 4000 BC, and developed a sophisticated architecture in mud-brick and stone, including the use of the true arch. The walls of Babylon were so massive they were quoted as a Wonder of the World. They developed extensive water systems; canals for transport and irrigation in the alluvial south, and catchment systems stretching for tens of kilometers in the hilly north. Their palaces had sophisticated drainage systems.

Writing was invented in Mesopotamia, using the cuneiform script. Many records on clay tablets and stone inscriptions have survived. These civilizations were early adopters of bronze technologies which they used for tools, weapons and monumental statuary. By 1200 BC they could cast objects 5 m long in a single piece.

Several of the six classic simple machines were invented in Mesopotamia. Mesopotamians have been credited with the invention of the wheel. The wheel and axle mechanism first appeared with the potter's wheel, invented in Mesopotamia (modern Iraq) during the 5th millennium BC. This led to the invention of the wheeled vehicle in Mesopotamia during the early 4th millennium BC. Depictions of wheeled wagons found on clay tablet pictographs at the Eanna district of Uruk are dated between 3700 and 3500 BC. The lever was used in the shadoof water-lifting device, the first crane machine, which appeared in Mesopotamia circa 3000 BC. and then in ancient Egyptian technology circa 2000 BC. The earliest evidence of pulleys date back to Mesopotamia in the early 2nd millennium BC.

The screw, the last of the simple machines to be invented, first appeared in Mesopotamia during the Neo-Assyrian period (911-609) BC. The Assyrian King Sennacherib (704–681 BC) claims to have invented automatic sluices and to have been the first to use water screw pumps, of up to 30 tons weight, which were cast using two-part clay molds rather than by the 'lost wax' process. The Jerwan Aqueduct (c. 688 BC) is made with stone arches and lined with waterproof concrete.

The Babylonian astronomical diaries spanned 800 years. They enabled meticulous astronomers to plot the motions of the planets and to predict eclipses.

The earliest evidence of water wheels and watermills date back to the ancient Near East in the 4th century BC, specifically in the Persian Empire before 350 BC, in the regions of Mesopotamia (Iraq) and Persia (Iran). This pioneering use of water power constituted the first human-devised motive force not to rely on muscle power (besides the sail).

Egypt

The Egyptians, known for building pyramids centuries before the creation of modern tools, invented and used many simple machines, such as the ramp to aid construction processes. Historians and archaeologists have found evidence that the pyramids were built using three of what is called the Six Simple Machines, from which all machines are based. These machines are the inclined plane, the wedge, and the lever, which allowed the ancient Egyptians to move millions of limestone blocks which weighed approximately 3.5 tons (7,000 lbs.) each into place to create structures like the Great Pyramid of Giza, which is 481 feet (146.7 meters) high.

They also made writing medium similar to paper from papyrus, which Joshua Mark states is the foundation for modern paper. Papyrus is a plant (cyperus papyrus) which grew in plentiful amounts in the Egyptian Delta and throughout the Nile River Valley during ancient times. The papyrus was harvested by field workers and brought to processing centers where it was cut into thin strips. The strips were then laid out side by side perpendicularly then covered in plant resin and the second layer of strips was laid on horizontally, then pressed together until the sheet was dry. The sheets were then joined together to form a roll and later used for writing.

Egyptian society made several significant advances during dynastic periods in many areas of technology. According to Hossam Elanzeery, they were the first civilization to use timekeeping devices such as sundials, shadow clocks, and obelisks and successfully leveraged their knowledge of astronomy to create a calendar model that society still uses today. They developed shipbuilding technology that saw them progress from papyrus reed vessels to cedar wood ships while also pioneering the use of rope trusses and stem-mounted rudders. The Egyptians also used their knowledge of anatomy to lay the foundation for many modern medical techniques and practiced the earliest known version of neuroscience. Elanzeery also states that they used and furthered mathematical science, as evidenced in the building of the pyramids.

Ancient Egyptians also invented and pioneered many food technologies that have become the basis of modern food technology processes. Based on paintings and reliefs found in tombs, as well as archaeological artifacts, scholars like Paul T Nicholson believe that the Ancient Egyptians established systematic farming practices, engaged in cereal processing, brewed beer and baked bread, processed meat, practiced viticulture and created the basis for modern wine production, and created condiments to complement, preserve and mask the flavors of their food.

Indus Valley

The Indus Valley Civilization, situated in a resource-rich area (in modern Pakistan and northwestern India), is notable for its early application of city planning, sanitation technologies, and plumbing. Indus Valley construction and architecture, called 'Vaastu Shastra', suggests a thorough understanding of materials engineering, hydrology, and sanitation.

China

The Chinese made many first-known discoveries and developments. Major technological contributions from China include early seismological detectors, matches, paper, Helicopter rotor, Raised-relief map, the double-action piston pump, cast iron, water powered blast furnace bellows, the iron plough, the multi-tube seed drill, the wheelbarrow, the parachute, the compass, the rudder, the crossbow, the South Pointing Chariot and gunpowder. China also developed deep well drilling, which they used to extract brine for making salt. Some of these wells, which were as deep as 900 meters, produced natural gas which was used for evaporating brine.

Other Chinese discoveries and inventions from the Medieval period include block printing, movable type printing, phosphorescent paint, endless power chain drive and the clock escapement mechanism. The solid-fuel rocket was invented in China about 1150, nearly 200 years after the invention of gunpowder (which acted as the rocket's fuel). Decades before the West's age of exploration, the Chinese emperors of the Ming Dynasty also sent large fleets on maritime voyages, some reaching Africa.

Hellenistic Mediterranean

The Hellenistic period of Mediterranean history began in the 4th century BC with Alexander's conquests, which led to the emergence of a Hellenistic civilization representing a synthesis of Greek and Near-Eastern cultures in the Eastern Mediterranean region, including the Balkans, Levant and Egypt. With Ptolemaic Egypt as its intellectual center and Greek as the lingua franca, the Hellenistic civilization included Greek, Egyptian, Jewish, Persian and Phoenician scholars and engineers who wrote in Greek.

Hellenistic engineers of the Eastern Mediterranean were responsible for a number of inventions and improvements to existing technology. The Hellenistic period saw a sharp increase in technological advancement, fostered by a climate of openness to new ideas, the blossoming of a mechanistic philosophy, and the establishment of the Library of Alexandria in Ptolemaic Egypt and its close association with the adjacent museion. In contrast to the typically anonymous inventors of earlier ages, ingenious minds such as Archimedes, Philo of Byzantium, Heron, Ctesibius, and Archytas remain known by name to posterity.

Ancient agriculture, as in any period prior to the modern age the primary mode of production and subsistence, and its irrigation methods, were considerably advanced by the invention and widespread application of a number of previously unknown water-lifting devices, such as the vertical water-wheel, the compartmented wheel, the water turbine, Archimedes' screw, the bucket-chain and pot-garland, the force pump, the suction pump, the double-action piston pump and quite possibly the chain pump.

In music, the water organ, invented by Ctesibius and subsequently improved, constituted the earliest instance of a keyboard instrument. In time-keeping, the introduction of the inflow clepsydra and its mechanization by the dial and pointer, the application of a feedback system and the escapement mechanism far superseded the earlier outflow clepsydra.

Innovations in mechanical technology included the newly devised right-angled gear, which would become particularly important to the operation of mechanical devices. Hellenistic engineers also devised automata such as suspended ink pots, automatic washstands, and doors, primarily as toys, which however featured new useful mechanisms such as the cam and gimbals.

The Antikythera mechanism, a kind of analogous computer working with a differential gear, and the astrolabe both show great refinement in astronomical science.

In other fields, ancient Greek innovations include the catapult and the gastraphetes crossbow in warfare, hollow bronze-casting in metallurgy, the dioptra for surveying, in infrastructure the lighthouse, central heating, a tunnel excavated from both ends by scientific calculations, and the ship trackway. In transport, great progress resulted from the invention of the winch and the odometer.

Further newly created techniques and items were spiral staircases, the chain drive, sliding calipers and showers.

Roman Empire

The Roman Empire expanded from Italia across the entire Mediterranean region between the 1st century BC and 1st century AD. Its most advanced and economically productive provinces outside of Italia were the Eastern Roman provinces in the Balkans, Asia Minor, Egypt, and the Levant, with Roman Egypt in particular being the wealthiest Roman province outside of Italia.

The Roman Empire developed an intensive and sophisticated agriculture, expanded upon existing iron working technology, created laws providing for individual ownership, advanced stone masonry technology, advanced road-building (exceeded only in the 19th century), military engineering, civil engineering, spinning and weaving and several different machines like the Gallic reaper that helped to increase productivity in many sectors of the Roman economy. Roman engineers were the first to build monumental arches, amphitheatres, aqueducts, public baths, true arch bridges, harbours, reservoirs and dams, vaults and domes on a very large scale across their Empire. Notable Roman inventions include the book (Codex), glass blowing and concrete. Because Rome was located on a volcanic peninsula, with sand which contained suitable crystalline grains, the concrete which the Romans formulated was especially durable. Some of their buildings have lasted 2000 years, to the present day.

In Roman Egypt, the inventor Hero of Alexandria was the first to experiment with a wind-powered mechanical device (see Heron's windwheel) and even created the earliest steam-powered device (the aeolipile), opening up new possibilities in harnessing natural forces. He also devised a vending machine. However, his inventions were primarily toys, rather than practical machines.

Inca, Maya, and Aztec

The engineering skills of the Inca and Maya were great, even by today's standards. An example of this exceptional engineering is the use of pieces weighing upwards of one ton in their stonework placed together so that not even a blade can fit into the cracks. Inca villages used irrigation canals and drainage systems, making agriculture very efficient. While some claim that the Incas were the first inventors of hydroponics, their agricultural technology was still soil based, if advanced.

Though the Maya civilization did not incorporate metallurgy or wheel technology in their architectural constructions, they developed complex writing and astronomical systems, and created beautiful sculptural works in stone and flint. Like the Inca, the Maya also had command of fairly advanced agricultural and construction technology. The Maya are also responsible for creating the first pressurized water system in Mesoamerica, located in the Maya site of Palenque.

The main contribution of the Aztec rule was a system of communications between the conquered cities and the ubiquity of the ingenious agricultural technology of chinampas. In Mesoamerica, without draft animals for transport (nor, as a result, wheeled vehicles), the roads were designed for travel on foot, just as in the Inca and Mayan civilizations. The Aztec, subsequently to the Maya, inherited many of the technologies and intellectual advancements of their predecessors: the Olmec (see Native American inventions and innovations).

Medieval to early modern

One of the most significant development of the Medieval era was the development of economies where water and wind power were more significant than animal and human muscle power. Most water and wind power was used for milling grain. Water power was also used for blowing air in blast furnace, pulping rags for paper making and for felting wool. The *Domesday Book* recorded 5,624 water mills in Great Britain in 1086, being about one per thirty families.

Islamic world

The Muslim caliphates united in trade large areas that had previously traded little, including the Middle East, North Africa, Central Asia, the Iberian Peninsula, and parts of the Indian subcontinent. The science and technology of previous empires in the region, including the Mesopotamian, Egyptian, Persian, Hellenistic and Roman empires, were inherited by the Muslim world, where Arabic replaced Syriac, Persian and Greek as the lingua franca of the region. Significant advances were made in the region during the Islamic Golden Age (8th-16th centuries).

The Arab Agricultural Revolution occurred during this period. It was a transformation in agriculture from the 8th to the 13th century in the Islamic region of the Old World. The economy established by Arab and other Muslim traders across the Old World enabled the diffusion of many crops and farming techniques throughout the Islamic world, as well as the adaptation of crops and techniques from and to regions outside it. Advances were made in animal husbandry, irrigation, and farming, with the help of new technology such as the windmill. These changes made agriculture much more productive, supporting population growth, urbanisation, and increased stratification of society.

Muslim engineers in the Islamic world made wide use of hydropower, along with early uses of tidal power, wind power, fossil fuels such as petroleum, and large factory complexes (*tiraz* in Arabic). A variety of industrial mills were employed in the Islamic world, including fulling mills, gristmills, hullers, sawmills, ship mills, stamp mills, steel mills, and tide mills. By the 11th century, every province throughout the Islamic world had these industrial mills in operation. Muslim engineers also employed water turbines and gears in mills and water-raising machines, and pioneered the use of dams as a source of water power, used to provide additional power to watermills and water-raising machines. Many of these technologies were transferred to medieval Europe.

Wind-powered machines used to grind grain and pump water, the windmill and wind pump, first appeared in what are now Iran, Afghanistan and Pakistan by the 9th century. They were used to grind grains and draw up water, and used in the gristmilling and sugarcane industries. Sugar mills first appeared in the medieval Islamic world. They were first driven by watermills, and then windmills from the 9th and 10th centuries in what are today Afghanistan, Pakistan and Iran. Crops such as almonds and citrus fruit were brought to Europe through Al-Andalus, and sugar cultivation was gradually adopted across Europe. Arab merchants dominated trade in the Indian Ocean until the arrival of the Portuguese in the 16th century.

The Muslim world adopted papermaking from China. The earliest paper mills appeared in Abbasid-era Baghdad during 794–795. The knowledge of gunpowder was also transmitted from China via predominantly Islamic countries, where formulas for pure potassium nitrate were developed.

The spinning wheel was invented in the Islamic world by the early 11th century. It was later widely adopted in Europe, where it was adapted into the spinning jenny, a key device during the Industrial Revolution. The crankshaft was invented by Al-Jazari in 1206, and is central to modern machinery such as the steam engine, internal combustion engine and automatic controls. The camshaft was also first described by Al-Jazari in 1206.

Early programmable machines were also invented in the Muslim world. The first music sequencer, a programmable musical instrument, was an automated flute player invented by the Banu Musa brothers, described in their *Book of Ingenious Devices*, in the 9th century.

In 1206, Al-Jazari invented programmable automata/robots. He described four automaton musicians, including two drummers operated by a programmable drum machine, where the drummer could be made to play different rhythms and different drum patterns. The castle clock, a hydropowered mechanical astronomical clock invented by Al-Jazari, was an early programmable analog computer.

In the Ottoman Empire, a practical impulse steam turbine was invented in 1551 by Taqi al-Din Muhammad ibn Ma'ruf in Ottoman Egypt. He described a method for rotating a spit by means of a jet of steam playing on rotary vanes around the periphery of a wheel. Known as a steam jack, a similar device for rotating a spit was also later described by John Wilkins in 1648.

Medieval Europe

While medieval technology has been long depicted as a step backwards in the evolution of Western technology, a generation of medievalists (like the American historian of science Lynn White) stressed from the 1940s onwards the innovative character of many medieval techniques.

Genuine medieval contributions include for example mechanical clocks, spectacles and vertical windmills. Medieval ingenuity was also displayed in the invention of seemingly inconspicuous items like the watermark or the functional button. In navigation, the foundation to the subsequent age of exploration was laid by the introduction of pintle-and-gudgeon rudders, lateen sails, the dry compass, the horseshoe and the astrolabe.

Significant advances were also made in military technology with the development of plate armour, steel crossbows and cannon. The Middle Ages are perhaps best known for their architectural heritage: While the invention of the rib vault and pointed arch gave rise to the high rising Gothic style, the ubiquitous medieval fortifications gave the era the almost proverbial title of the 'age of castles'.

Papermaking, a 2nd-century Chinese technology, was carried to the Middle East when a group of Chinese papermakers were captured in the 8th century. Papermaking technology was spread to Europe by the Umayyad conquest of Hispania. A paper mill was established in Sicily in the 12th century. In Europe the fiber to make pulp for making paper was obtained from linen and cotton rags. Lynn Townsend White Jr. credited the spinning wheel with increasing the supply of rags, which led to cheap paper, which was a factor in the development of printing.

Renaissance technology

Before the development of modern engineering, mathematics was used by artisans and craftsmen, such as millwrights, clock makers, instrument makers and surveyors. Aside from these professions, universities were not believed to have had much practical significance to technology.

A standard reference for the state of mechanical arts during the Renaissance is given in the mining engineering treatise *De re metallica* (1556), which also contains sections on geology, mining and chemistry. *De re metallica* was the standard chemistry reference for the next 180 years. Among the water powered mechanical devices in use were ore stamping mills, forge hammers, blast bellows, and suction pumps.

Due to the casting of cannon, the blast furnace came into widespread use in France in the mid 15th century. The blast furnace had been used in China since the 4th century BC.

The invention of the movable cast metal type printing press, whose pressing mechanism was adapted from an olive screw press, (c. 1441) lead to a tremendous increase in the number of books and the number of titles published. Movable ceramic type had been used in China for a few centuries and woodblock printing dated back even further.

The era is marked by such profound technical advancements like linear perceptivity, double shell domes or Bastion fortresses. Note books of the Renaissance artist-engineers such as Taccola and Leonardo da Vinci give a deep insight into the mechanical technology then known and applied. Architects and engineers were inspired by the structures of Ancient Rome, and men like Brunelleschi created the large dome of Florence Cathedral as a result.

He was awarded one of the first patents ever issued in order to protect an ingenious crane he designed to raise the large masonry stones to the top of the structure. Military technology developed rapidly with the widespread use of the cross-bow and ever more powerful artillery, as the city-states of Italy were usually in conflict with one another. Powerful families like the Medici were strong patrons of the arts and sciences. Renaissance science spawned the Scientific Revolution; science and technology began a cycle of mutual advancement.

Age of Exploration

An improved sailing ship, the (nau or carrack), enabled the Age of Exploration with the European colonization of the Americas, epitomized by Francis Bacon's *New Atlantis*. Pioneers like Vasco da Gama, Cabral, Magellan and Christopher Columbus explored the world in search of new trade routes for their goods and contacts with Africa, India and China to shorten the journey compared with traditional routes overland. They produced new maps and charts which enabled following mariners to explore further with greater confidence. Navigation was generally difficult, however, owing to the problem of longitude and the absence of accurate chronometers. European powers rediscovered the idea of the civil code, lost since the time of the Ancient Greeks.

Pre-Industrial Revolution

The stocking frame, which was invented in 1598, increased a knitter's number of knots per minute from 100 to 1000.

Mines were becoming increasingly deep and were expensive to drain with horse powered bucket and chain pumps and wooden piston pumps. Some mines used as many as 500 horses. Horse-powered pumps were replaced by the Savery steam pump (1698) and the Newcomen steam engine (1712).

Industrial Revolution (1760–1830s)

- The revolution was driven by cheap energy in the form of coal, produced in ever-increasing amounts from the abundant resources of Britain. The British Industrial Revolution is characterized by developments in the areas of textile machinery, mining, metallurgy and transport the steam engine and the invention of machine tools. Before invention of machinery to spin yarn and weave cloth, spinning was done using the spinning wheel and weaving was done on a hand-and-foot-operated loom. It took from three to five spinners to supply one weaver. The invention of the flying shuttle in 1733 doubled the output of a weaver, creating a shortage of spinners. The spinning frame for wool was invented in 1738. The spinning jenny, invented in 1764, was a machine that used multiple spinning wheels; however, it produced low quality thread. The water frame patented by Richard Arkwright in 1767, produced a better quality thread than the spinning jenny. The spinning mule, patented in 1779 by Samuel Crompton, produced a high quality thread. The power loom was invented by Edmund Cartwright in 1787.In the mid 1750s the steam engine was applied to the water power-constrained iron, copper and lead industries for powering blast bellows. These industries were located near the mines, some of which were using steam engines for mine pumping. Steam engines were too powerful for leather bellows, so cast iron blowing cylinders were developed in 1768. Steam powered blast furnaces achieved higher temperatures, allowing the use of more lime in iron blast furnace feed. (Lime rich slag was not free-flowing at the previously used temperatures.) With a sufficient lime ratio, sulfur from coal or coke fuel reacts with the slag so that the sulfur does not contaminate the iron. Coal and coke were cheaper and more abundant fuel. As a result, iron production rose significantly during the last decades of the 18th century. Coal converted to coke fueled higher temperature blast furnaces and produced cast iron in much larger amounts than before, allowing the creation of a range of structures such as The Iron Bridge. Cheap coal meant that industry was no longer constrained by water resources driving the mills, although it continued as a valuable source of power.

The steam engine helped drain the mines, so more coal reserves could be accessed, and the output of coal increased. The development of the high-pressure steam engine made locomotives possible, and a transport revolution followed. The steam engine which had existed since the early 18th century, was practically applied to both steamboat and railway transportation. The Liverpool and Manchester Railway, the first purpose built railway line, opened in 1830, the Rocket locomotive of Robert Stephenson being one of its first working locomotives used.

Manufacture of ships' pulley blocks by all-metal machines at the Portsmouth Block Mills in 1803 instigated the age of sustained mass production. Machine tools used by engineers to manufacture parts began in the first decade of the century, notably by Richard Roberts and Joseph Whitworth. The development of interchangeable parts through what is now called the American system of manufacturing began in the firearms industry at the U.S Federal arsenals in the early 19th century, and became widely used by the end of the century.

Second Industrial Revolution (1860s–1914)

The 19th century saw astonishing developments in transportation, construction, manufacturing and communication technologies originating in Europe. After a recession at the end of the 1830s and a general slowdown in major inventions, the Second Industrial Revolution was a period of rapid innovation and industrialization that began in the 1860s or around 1870 and lasted until World War I. It included rapid development of chemical, electrical, petroleum, and steel technologies connected with highly structured technology research.

Telegraphy developed into a practical technology in the 19th century to help run the railways safely. Along with the development of telegraphy was the patenting of the first telephone.

March 1876 marks the date that Alexander Graham Bell officially patented his version of an "electric telegraph". Although Bell is noted with the creation of the telephone, it is still debated about who actually developed the first working model.

Building on improvements in vacuum pumps and materials research, incandescent light bulbs became practical for general use in the late 1870s. This invention had a profound effect on the workplace because factories could now have second and third shift workers.

Shoe production was mechanized during the mid 19th century. Mass production of sewing machines and agricultural machinery such as reapers occurred in the mid to late 19th century. Bicycles were mass-produced beginning in the 1880s.

Steam-powered factories became widespread, although the conversion from water power to steam occurred in England earlier than in the U.S. Ironclad warships were found in battle starting in the 1860s, and played a role in the opening of Japan and China to trade with the West.

20th century

Mass production brought automobiles and other high-tech goods to masses of consumers. Military research and development sped advances including electronic computing and jet engines. Radio and telephony greatly improved and spread to larger populations of users, though near-universal access would not be possible until mobile phones became affordable to developing world residents in the late 2000s and early 2010s.

Energy and engine technology improvements included nuclear power, developed after the Manhattan project which heralded the new Atomic Age. Rocket development led to long range missiles and the first space age that lasted from the 1950s with the launch of Sputnik to the mid-1980s.

Electrification spread rapidly in the 20th century. At the beginning of the century electric power was for the most part only available to wealthy people in a few major cities, but by the time the World Wide Web was invented in 1990 an estimated 62 percent of homes worldwide had electric power, including about a third of households in the rural developing world.

Birth control also became widespread during the 20th century. Electron microscopes were very powerful by the late 1970s and genetic theory and knowledge were expanding, leading to developments in genetic engineering.

The first "test tube baby" Louise Brown was born in 1978, which led to the first successful gestational surrogacy pregnancy in 1985 and the first pregnancy by ICSI in 1991, which is the implanting of a single sperm into an egg.

Preimplantation genetic diagnosis was first performed in late 1989 and led to successful births in July 1990. These procedures have become relatively common.

The massive data analysis resources necessary for running transatlantic research programs such as the Human Genome Project and the Large Electron–Positron Collider led to a necessity for distributed communications, causing Internet protocols to be more widely adopted by researchers and also creating a justification for Tim Berners-Lee to create the World Wide Web.

Vaccination spread rapidly to the developing world from the 1980s onward due to many successful humanitarian initiatives, greatly reducing childhood mortality in many poor countries with limited medical resources.

The US National Academy of Engineering, by expert vote, established the following ranking of the most important technological developments of the 20th century:

- Electrification
- Automobile
- Airplane
- Water supply and Distribution
- Electronics
- Radio and Television
- Mechanized agriculture
- Computers
- Telephone
- Air Conditioning and Refrigeration
- Highways
- Spacecraft

- Internet
- Imaging technology
- Household appliances
- Health technology
- Petroleum and Petrochemical technologies
- Laser and Fiber Optics
- Nuclear technology
- Materials science

21st century

In the early 21st century research is ongoing into quantum computers, gene therapy (introduced 1990), 3D printing (introduced 1981), nanotechnology (introduced 1985), bioengineering/biotechnology, nuclear technology, advanced materials (e.g., graphene), the scramjet and drones (along with railguns and high-energy laser beams for military uses), superconductivity, the memristor, and green technologies such as alternative fuels (e.g., fuel cells, self-driving electric and plug-in hybrid cars), augmented reality devices and wearable electronics, artificial intelligence, and more efficient and powerful LEDs, solar cells, integrated circuits, wireless power devices, engines, and batteries.

Perhaps the greatest research tool built in the 21st century is the Large Hadron Collider, the largest single machine ever built. The understanding of particle physics is expected to expand with better instruments including larger particle accelerators such as the LHC and better neutrino detectors. Dark matter is sought via underground detectors and observatories like LIGO have started to detect gravitational waves.

Genetic engineering technology continues to improve, and the importance of epigenetics on development and inheritance has also become increasingly recognized.

New spaceflight technology and spacecraft are also being developed, like the Boeing's Orion and SpaceX's Dragon 2. New, more capable space telescopes, such as the James Webb Telescope, to be launched to orbit in late 2021, and the Colossus Telescope are being designed. The International Space Station was completed in the 2000s, and NASA and ESA plan a human mission to Mars in the 2030s. The Variable Specific Impulse Magnetoplasma Rocket (VASIMR) is an electro-magnetic thruster for spacecraft propulsion and is expected to be tested in 2015.

Breakthrough Initiatives, together with famed physicist Stephen Hawking, plan to send the first ever spacecraft to visit another star, which will consist of numerous super-light chips driven by Electric propulsion in the 2030s, and receive images of the Proxima Centauri system, along with, possibly, the potentially habitable planet Proxima Centauri b, by midcentury.

2004 saw the first crewed commercial spaceflight when Mike Melvill crossed the boundary of space on June 21, 2004.

Chapter 2

Neolithic Revolution

The Neolithic Revolution, or the (First) Agricultural Revolution, was the wide-scale transition of many human cultures during the Neolithic period from a lifestyle of hunting and gathering to one of agriculture and settlement, making an increasingly large population possible. These settled communities permitted humans to observe and experiment with plants, learning how they grew and developed. This new knowledge led to the domestication of plants.

Archaeological data indicates that the domestication of various types of plants and animals happened in separate locations worldwide, starting in the geological epoch of the Holocene 11,700 years ago. It was the world's first historically verifiable revolution in agriculture. The Neolithic Revolution greatly narrowed the diversity of foods available, resulting in a downturn in the quality of human nutrition.

The Neolithic Revolution involved far more than the adoption of a limited set of food-producing techniques. During the next millennia it transformed the small and mobile groups of hunter-gatherers that had hitherto dominated human pre-history into sedentary (non-nomadic) societies based in built-up villages and towns. These societies radically modified their natural environment by means of specialized food-crop cultivation, with activities such as irrigation and deforestation which allowed the production of surplus food. Other developments that are found very widely during this era are the domestication of animals, pottery, polished stone tools, and rectangular houses. In many regions, the adoption of agriculture by prehistoric societies caused episodes of rapid population growth, a phenomenon known as the Neolithic demographic transition.

These developments, sometimes called the **Neolithic package**, provided the basis for centralized administrations and political structures, hierarchical ideologies, depersonalized systems of knowledge (e.g. writing), densely populated settlements, specialization and division of labour, more trade, the development of non-portable art and architecture, and greater property ownership. The earliest known civilization developed in Sumer in southern Mesopotamia (c. 6,500 BP); its emergence also heralded the beginning of the Bronze Age.

The relationship of the above-mentioned Neolithic characteristics to the onset of agriculture, their sequence of emergence, and empirical relation to each other at various Neolithic sites remains the subject of academic debate, and varies from place to place, rather than being the outcome of universal laws of social evolution. The Levant saw the earliest developments of the Neolithic Revolution from around 10,000 BCE, followed by sites in the wider Fertile Crescent.

Background

Hunter-gatherers had different subsistence requirements and lifestyles from agriculturalists. They resided in temporary shelters and were highly mobile, moving in small groups and had limited contact with outsiders. Their diet was well-balanced and depended on what the environment provided each season. Because the advent of agriculture made it possible to support larger groups, agriculturalists lived in more permanent dwellings in areas that were more densely populated than could be supported by the hunter-gatherer lifestyle. The development of trading networks and complex societies brought them into contact with outside groups.

However, population increase did not necessarily correlate with improved health. Reliance on a single crop can adversely affect health even while making it possible to support larger numbers of people. Maize is deficient in certain essential amino acids (lysine and tryptophan) and is a poor source of iron. The phytic acid it contains may inhibit nutrient absorption. Other factors that likely affected the health of early agriculturalists and their domesticated livestock would have been increased numbers of parasites and disease-bearing pests associated with human waste and contaminated food and water supplies. Fertilizers and irrigation may have increased crop yields but also would have promoted proliferation of insects and bacteria in the local environment while grain storage attracted additional insects and rodents.

Agricultural transition

The term 'neolithic revolution' was coined by V. Gordon Childe in his 1936 book *Man Makes Himself*. Childe introduced it as the first in a series of agricultural revolutions in Middle Eastern history, calling it a "revolution" to denote its significance, the degree of change to communities adopting and refining agricultural practices.

The beginning of this process in different regions has been dated from 10,000 to 8,000 BCE in the Fertile Crescent, and perhaps 8000 BCE in the Kuk Early Agricultural Site of Papua New Guinea in Melanesia. Everywhere, this transition is associated with a change from a largely nomadic hunter-gatherer way of life to a more settled, agrarian one, with the domestication of various plant and animal species – depending on the species locally available, and probably influenced by local culture. Recent archaeological research suggests that in some regions, such as the Southeast Asian peninsula, the transition from hunter-gatherer to agriculturalist was not linear, but region-specific.

There are several theories (not mutually exclusive) as to factors that drove populations to take up agriculture. The most prominent are:

- The Oasis Theory, originally proposed by Raphael Pumpelly in 1908, popularized by V. Gordon Childe in 1928 and summarised in Childe's book *Man Makes Himself*. This theory maintains that as the climate got drier due to the Atlantic depressions shifting northward, communities contracted to oases where they were forced into close association with animals, which were then domesticated together with planting of seeds. However, today this theory has little support amongst archaeologists because subsequent climate data suggests that the region was getting wetter rather than drier.
- The Hilly Flanks hypothesis, proposed by Robert Braidwood in 1948, suggests that agriculture began in the hilly flanks of the Taurus and Zagros mountains, where the climate was not drier as Childe had believed, and fertile land supported a

variety of plants and animals amenable to domestication.

- The Feasting model by Brian Hayden suggests that agriculture was driven by ostentatious displays of power, such as giving feasts, to exert dominance. This required assembling large quantities of food, which drove agricultural technology.
- The Demographic theories proposed by Carl Sauer and adapted by Lewis Binford and Kent Flannery posit an increasingly sedentary population that expanded up to the carrying capacity of the local environment and required more food than could be gathered. Various social and economic factors helped drive the need for food.
- The evolutionary/intentionality theory, developed by David Rindos and others, views agriculture as an evolutionary adaptation of plants and humans. Starting with domestication by protection of wild plants, it led to specialization of location and then full-fledged domestication.
- Peter Richerson, Robert Boyd, and Robert Bettinger make a case for the development of agriculture coinciding with an increasingly stable climate at the beginning of the Holocene. Ronald Wright's book and Massey Lecture Series *A Short History of Progress* popularized this hypothesis.
- Leonid Grinin argues that whatever plants were cultivated, the independent invention of agriculture always took place in special natural environments (e.g., South-East Asia). It is supposed that the cultivation of cereals started somewhere in the Near East: in the hills of Israel or Egypt. So Grinin dates

the beginning of the agricultural revolution within the interval 12,000 to 9,000 BP, though in some cases the first cultivated plants or domesticated animals' bones are even of a more ancient age of 14–15 thousand years ago.

- Andrew Moore suggested that the Neolithic Revolution originated over long periods of development in the Levant, possibly beginning during the Epipaleolithic. In *"A Reassessment of the Neolithic Revolution"*, Frank Hole further expanded the relationship between plant and animal domestication. He suggested the events could have occurred independently over different periods of time, in as yet unexplored locations. He noted that no transition site had been found documenting the shift from what he termed immediate and delayed return social systems. He noted that the full range of domesticated animals (goats, sheep, cattle and pigs) were not found until the sixth millennium at Tell Ramad. Hole concluded that *"close attention should be paid in future investigations to the western margins of the Euphrates basin, perhaps as far south as the Arabian Peninsula, especially where wadis carrying Pleistocene rainfall runoff flowed."*

Early harvesting of cereals (23,000 BP)

Use-wear analysis of five glossed flint blades found at Ohalo II, a 23,000-years-old fisher-hunter-gatherers' camp on the shore of the Sea of Galilee, Northern Israel, provides the earliest evidence for the use of composite cereal harvesting tools. The Ohalo site is at the junction of the Upper Paleolithic and the Early Epipaleolithic, and has been attributed to both periods.

The wear traces indicate that tools were used for harvesting near-ripe semi-green wild cereals, shortly before grains are ripe and disperse naturally. The studied tools were not used intensively, and they reflect two harvesting modes: flint knives held by hand and inserts hafted in a handle. The finds shed new light on cereal harvesting techniques some 8,000 years before the Natufian and 12,000 years before the establishment of sedentary farming communities in the Near East. Furthermore, the new finds accord well with evidence for the earliest ever cereal cultivation at the site and the use of stone-made grinding implements.

Domestication of plants

- Once agriculture started gaining momentum, around 9000 BP, human activity resulted in the selective breeding of cereal grasses (beginning with emmer, einkorn and barley), and not simply of those that favoured greater caloric returns through larger seeds. Plants with traits such as small seeds or bitter taste were seen as undesirable. Plants that rapidly shed their seeds on maturity tended not to be gathered at harvest, therefore not stored and not seeded the following season; successive years of harvesting spontaneously selected for strains that retained their edible seeds longer. Daniel Zohary identified several plant species as "pioneer crops" or Neolithic founder crops. He highlighted the importance of wheat, barley and rye, and suggested that domestication of flax, peas, chickpeas, bitter vetch and lentils came a little later. Based on analysis of the genes of domesticated plants, he preferred theories of a single, or at most a very small number of domestication events for each taxon that spread in an arc from the Levantine corridor around the Fertile Crescent and later into Europe. Gordon Hillman and Stuart Davies carried out experiments with varieties of wild wheat to show that the process of domestication would have occurred over a relatively short period of between 20 and 200 years. Some of the pioneering attempts failed at first and crops were abandoned, sometimes to be taken up again and successfully domesticated thousands of years later: rye, tried and abandoned in Neolithic Anatolia, made its way to Europe as weed seeds and was successfully domesticated in Europe, thousands of years after the earliest agriculture. Wild lentils presented a different problem: most of the wild seeds do not germinate in the first year; the first evidence of lentil domestication, breaking dormancy in their first year, appears in the early Neolithic at Jerf el Ahmar (in modern Syria), and lentils quickly spread south to the Netiv HaGdud site in the Jordan Valley. The process of domestication allowed the founder crops to adapt and eventually become larger, more easily harvested, more dependable in storage and more useful to the human population.

Selectively propagated figs, wild barley and wild oats were cultivated at the early Neolithic site of Gilgal I, where in 2006 archaeologists found caches of seeds of each in quantities too large to be accounted for even by intensive gathering, at strata datable to c. 11,000 years ago. Some of the plants tried and then abandoned during the Neolithic period in the Ancient Near East, at sites like Gilgal, were later successfully domesticated in other parts of the world.

Once early farmers perfected their agricultural techniques like irrigation (traced as far back as the 6th millennium BCE in Khuzistan), their crops yielded surpluses that needed storage. Most hunter-gatherers could not easily store food for long due to their migratory lifestyle, whereas those with a sedentary dwelling could store their surplus grain. Eventually granaries were developed that allowed villages to store their seeds longer. So with more food, the population expanded and communities developed specialized workers and more advanced tools.

The process was not as linear as was once thought, but a more complicated effort, which was undertaken by different human populations in different regions in many different ways.

Spread of crops: the case of barley

One of the world's most important crops, barley, was domesticated in the Near East around 11,000 years ago (c. 9,000 BCE). Barley is a highly resilient crop, able to grow in varied and marginal environments, such as in regions of high altitude and latitude. Archaeobotanical evidence shows that barley had spread throughout Eurasia by 2,000 BCE. To further elucidate the routes by which barley cultivation was spread through Eurasia, genetic analysis was used to determine genetic diversity and population structure in extant barley taxa. Genetic analysis shows that cultivated barley spread through Eurasia via several different routes, which were most likely separated in both time and space.

Development and diffusion

Beginnings in the Levant

Agriculture appeared first in Southwest Asia about 2,000 years later, around 10,000–9,000 years ago. The region was the centre of domestication for three cereals (einkorn wheat, emmer wheat and barley), four legumes (lentil, pea, bitter vetch and chickpea), and flax. Domestication was a slow process that unfolded across multiple regions, and was preceded by centuries if not millennia of pre-domestication cultivation.

Finds of large quantities of seeds and a grinding stone at the Epipalaeolithic site of Ohalo II, dating to around 19,400 BP, has shown some of the earliest evidence for advanced planning of plants for food consumption and suggests that humans at Ohalo II processed the grain before consumption. Tell Aswad is the oldest site of agriculture, with domesticated emmer wheat dated to 10,800 BP. Soon after came hulled, two-row barley – found domesticated earliest at Jericho in the Jordan valley and at Iraq ed-Dubb in Jordan. Other sites in the Levantine corridor that show early evidence of agriculture include Wadi Faynan 16 and Netiv Hagdud. Jacques Cauvin noted that the settlers of Aswad did not domesticate on site, but *"arrived, perhaps from the neighbouring Anti-Lebanon, already equipped with the seed for planting"*. In the Eastern Fertile Crescent, evidence of cultivation of wild plants has been found in Choga

Gholan in Iran dated to 12,000 BP, suggesting there were multiple regions in the Fertile Crescent where domestication evolved roughly contemporaneously. The Heavy Neolithic Qaraoun culture has been identified at around fifty sites in Lebanon around the source springs of the River Jordan, but never reliably dated.

Europe

Archeologists trace the emergence of food-producing societies in the Levantine region of southwest Asia at the close of the last glacial period around 12,000 BCE, and developed into a number of regionally distinctive cultures by the eighth millennium BCE. Remains of food-producing societies in the Aegean have been carbon-dated to around 6500 BCE at Knossos, Franchthi Cave, and a number of mainland sites in Thessaly. Neolithic groups appear soon afterwards in the Balkans and south-central Europe. The Neolithic cultures of southeastern Europe (the Balkans and the Aegean) show some continuity with groups in southwest Asia and Anatolia (e.g., Çatalhöyük).

Current evidence suggests that Neolithic material culture was introduced to Europe via western Anatolia. All Neolithic sites in Europe contain ceramics, and contain the plants and animals domesticated in Southwest Asia: einkorn, emmer, barley, lentils, pigs, goats, sheep, and cattle. Genetic data suggest that no independent domestication of animals took place in Neolithic Europe, and that all domesticated animals were originally domesticated in Southwest Asia. The only domesticate not from Southwest Asia was broomcorn millet, domesticated in East Asia.The earliest evidence of cheese-making dates to 5500 BCE in Kujawy, Poland.

The diffusion across Europe, from the Aegean to Britain, took about 2,500 years (8500–6000 BP). The Baltic region was penetrated a bit later, around 5500 BP, and there was also a delay in settling the Pannonian plain. In general, colonization shows a "saltatory" pattern, as the Neolithic advanced from one patch of fertile alluvial soil to another, bypassing mountainous areas. Analysis of radiocarbon dates show clearly that Mesolithic and Neolithic populations lived side by side for as much as a millennium in many parts of Europe, especially in the Iberian peninsula and along the Atlantic coast.

Carbon 14 evidence

The spread of the Neolithic from the Near East Neolithic to Europe was first studied quantitatively in the 1970s, when a sufficient number of Carbon 14 age determinations for early Neolithic sites had become available. Ammerman and Cavalli-Sforza discovered a linear relationship between the age of an Early Neolithic site and its distance from the conventional source in the Near East (Jericho), demonstrating that the Neolithic spread at an average speed of about 1 km/yr. More recent studies confirm these results and yield the speed of 0.6–1.3 km/yr (at 95% confidence level).

Analysis of mitochondrial DNA

Since the original human expansions out of Africa 200,000 years ago, different prehistoric and historic migration events have taken place in Europe. Considering that the movement of the people implies a consequent movement of their genes, it is possible to estimate the impact of these migrations through the genetic analysis of human populations. Agricultural and husbandry practices originated 10,000 years ago in a region of the Near East known as the Fertile Crescent. According to the archaeological record this phenomenon, known as “Neolithic”, rapidly expanded from these territories into Europe. However, whether this diffusion was accompanied or not by human migrations is greatly debated. Mitochondrial DNA – a type of maternally inherited DNA located in the cell cytoplasm – was recovered from the remains of Pre-Pottery Neolithic B (PPNB) farmers in the Near East and then compared to available data from other Neolithic populations in Europe and also to modern populations from South Eastern Europe and the Near East. The obtained results show that substantial human migrations were involved in the Neolithic spread and suggest that the first Neolithic farmers entered Europe following a maritime route through Cyprus and the Aegean Islands.

South Asia

The earliest Neolithic sites in South Asia are Bhirrana in Haryana dated to 7570–6200 BCE, and Mehrgarh, dated to between 6500 and 5500 BP, in the Kachi plain of Baluchistan, Pakistan; the site has evidence of farming (wheat and barley) and herding (cattle, sheep and goats).

There is strong evidence for causal connections between the Near-Eastern Neolithic and that further east, up to the Indus Valley. There are several lines of evidence that support the idea of connection between the Neolithic in the Near East and in the Indian subcontinent. The prehistoric site of Mehrgarh in

Baluchistan (modern Pakistan) is the earliest Neolithic site in the north-west Indian subcontinent, dated as early as 8500 BCE. Neolithic domesticated crops in Mehrgarh include more than barley and a small amount of wheat. There is good evidence for the local domestication of barley and the zebu cattle at Mehrgarh, but the wheat varieties are suggested to be of Near-Eastern origin, as the modern distribution of wild varieties of wheat is limited to Northern Levant and Southern Turkey. A detailed satellite map study of a few archaeological sites in the Baluchistan and Khybar Pakhtunkhwa regions also suggests similarities in early phases of farming with sites in Western Asia. Pottery prepared by sequential slab construction, circular fire pits filled with burnt pebbles, and large granaries are common to both Mehrgarh and many Mesopotamian sites. The postures of the skeletal remains in graves at Mehrgarh bear strong resemblance to those at Ali Kosh in the Zagros Mountains of southern Iran. Despite their scarcity, the 14C and archaeological age determinations for early Neolithic sites in Southern Asia exhibit remarkable continuity across the vast region from the Near East to the Indian Subcontinent, consistent with a systematic eastward spread at a speed of about 0.65 km/yr.

In East Asia

Agriculture in Neolithic China can be separated into two broad regions, Northern China and Southern China.

The agricultural center in northern China is believed to be the homelands of the early Sino-Tibetan-speakers, associated with the Houli, Peiligang, Cishan, and Xinglongwa cultures, clustered around the Yellow River basin. It was the domestication center for foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*), with early evidence of domestication approximately 8,000 years ago, and widespread cultivation 7,500 years ago. (Soybean was also domesticated in northern China 4,500 years ago. Orange and peach also originated in China, being cultivated around 2500 BCE.)

The agricultural centers in southern China are clustered around the Yangtze River basin. Rice was domesticated in this region, together with the development of paddy field cultivation, between 13,500 and 8,200 years ago.

There are two possible centers of domestication for rice. The first, and most likely, is in the lower Yangtze River, believed to be the homelands of early Austronesian speakers and associated with the Kauhuqiao, Hemudu, Majiabang, and Songze cultures. It is characterized by typical pre-Austronesian features, including stilt houses, jade carving, and boat technologies. Their diet were also supplemented by acorns, water chestnuts, foxnuts, and pig domestication. The second is in the middle Yangtze River, believed to be the homelands of the early Hmong-Mien-speakers and associated with the Pengtoushan and Daxi cultures. Both of these regions were heavily populated and had regular trade contacts with each other, as well as with early Austroasiatic speakers to the west, and early Kra-Dai speakers to the south, facilitating the spread of rice cultivation throughout southern China.

The millet and rice-farming cultures also first came into contact with each other at around 9,000 to 7,000 BP, resulting in a corridor between the millet and rice cultivation centers where both rice and millet were cultivated. At around 5,500 to

4,000 BP, there was increasing migration into Taiwan from the early Austronesian Dapenkeng culture, bringing rice and millet cultivation technology with them. During this period, there is evidence of large settlements and intensive rice cultivation in Taiwan and the Penghu Islands, which may have resulted in overexploitation. Bellwood (2011) proposes that this may have been the impetus of the Austronesian expansion which started with the migration of the Austronesian-speakers from Taiwan to the Philippines at around 5,000 BP.

Austronesians carried rice cultivation technology to Island Southeast Asia along with other domesticated species. The new tropical island environments also had new food plants that they exploited. They carried useful plants and animals during each colonization voyage, resulting in the rapid introduction of domesticated and semi-domesticated species throughout Oceania. They also came into contact with the early agricultural centers of Papuan-speaking populations of New Guinea as well as the Dravidian-speaking regions of South India and Sri Lanka by around 3,500 BP. They acquired further cultivated food plants like bananas and pepper from them, and in turn introduced Austronesian technologies like wetland cultivation and outrigger canoes. During the 1st millennium CE, they also colonized Madagascar and the Comoros, bringing Southeast Asian food plants, including rice, to East Africa.

In Africa

On the African continent, three areas have been identified as independently developing agriculture: the Ethiopian highlands, the Sahel and West Africa. By contrast, Agriculture in the Nile River Valley is thought to have developed from the original

Neolithic Revolution in the Fertile Crescent. Many grinding stones are found with the early Egyptian Sebilian and Mechian cultures and evidence has been found of a neolithic domesticated crop-based economy dating around 7,000 BP. Unlike the Middle East, this evidence appears as a "false dawn" to agriculture, as the sites were later abandoned, and permanent farming then was delayed until 6,500 BP with the Tasian culture and Badarian culture and the arrival of crops and animals from the Near East.

Bananas and plantains, which were first domesticated in Southeast Asia, most likely Papua New Guinea, were re-domesticated in Africa possibly as early as 5,000 years ago. Asian yams and taro were also cultivated in Africa.

The most famous crop domesticated in the Ethiopian highlands is coffee. In addition, khat, ensete, noog, teff and finger millet were also domesticated in the Ethiopian highlands. Crops domesticated in the Sahel region include sorghum and pearl millet. The kola nut was first domesticated in West Africa. Other crops domesticated in West Africa include African rice, yams and the oil palm. Agriculture spread to Central and Southern Africa in the Bantu expansion during the 1st millennium BCE to 1st millennium CE.

In the Americas

Maize (corn), beans and squash were among the earliest crops domesticated in Mesoamerica: squash as early as 6000 BCE, beans no later than 4000 BCE, and maize beginning about 4000 BCE. Potatoes and manioc were domesticated in South America. In what is now the eastern United States, Native

Americans domesticated sunflower, sumpweed and goosefoot around 2500 BCE. Sedentary village life based on farming did not develop until the "the formative period" in the second millennium BCE.

In New Guinea

Evidence of drainage ditches at Kuk Swamp on the borders of the Western and Southern Highlands of Papua New Guinea indicates cultivation of taro and a variety of other crops, dating back to 11,000 BP. Two potentially significant economic species, taro (*Colocasia esculenta*) and yam (*Dioscorea* sp.), have been identified dating at least to 10,200 calibrated years before present (cal BP). Further evidence of bananas and sugarcane dates to 6,950 to 6,440 BCE. This was at the altitudinal limits of these crops, and it has been suggested that cultivation in more favourable ranges in the lowlands may have been even earlier. CSIRO has found evidence that taro was introduced into the Solomon Islands for human use, from 28,000 years ago, making taro cultivation the earliest crop in the world. It seems to have resulted in the spread of the Trans–New Guinea languages from New Guinea east into the Solomon Islands and west into Timor and adjacent areas of Indonesia. This seems to confirm the theories of Carl Sauer who, in "Agricultural Origins and Dispersals", suggested as early as 1952 that this region was a centre of early agriculture.

Domestication of animals

When hunter-gathering began to be replaced by sedentary food production it became more efficient to keep animals close at hand. Therefore, it became necessary to bring animals permanently to their settlements, although in many cases there was a distinction between relatively sedentary farmers and nomadic herders. The animals' size, temperament, diet, mating patterns, and life span were factors in the desire and success in domesticating animals. Animals that provided milk, such as cows and goats, offered a source of protein that was renewable and therefore quite valuable. The animal's ability as a worker (for example ploughing or towing), as well as a food source, also had to be taken into account. Besides being a direct source of food, certain animals could provide leather, wool, hides, and fertilizer. Some of the earliest domesticated animals included dogs (East Asia, about 15,000 years ago), sheep, goats, cows, and pigs.

Domestication of animals in the Middle East

The Middle East served as the source for many animals that could be domesticated, such as sheep, goats and pigs. This area was also the first region to domesticate the dromedary. Henri Fleisch discovered and termed the Shepherd Neolithic flint industry from the Bekaa Valley in Lebanon and suggested that it could have been used by the earliest nomadic shepherds. He dated this industry to the Epipaleolithic or Pre-Pottery Neolithic as it is evidently not Paleolithic, Mesolithic or even Pottery Neolithic. The presence of these animals gave the region a large advantage in cultural and economic development. As the climate in the Middle East changed and became drier, many of the farmers were forced to leave, taking their domesticated animals with them. It was this massive emigration from the Middle East that later helped distribute these animals to the rest of Afroeurasia. This emigration was mainly on an east–west axis of similar climates, as crops usually have a narrow optimal climatic range outside of which they cannot grow for reasons of light or rain changes. For instance, wheat does not normally grow in tropical climates, just like tropical crops such as bananas do not grow in colder climates. Some authors, like Jared Diamond, have postulated that this east–west axis is the main reason why plant and animal domestication spread so quickly from the Fertile Crescent to the rest of Eurasia and North Africa, while it did not reach through the north–south axis of Africa to reach the Mediterranean climates of South Africa, where temperate crops were successfully imported by ships in the last 500 years. Similarly, the African Zebu of central Africa and the domesticated bovines of the fertile-crescent – separated by the dry sahara desert – were not introduced into each other's region.

Consequences

Social change

Despite the significant technological advance, the Neolithic revolution did not lead immediately to a rapid growth of population. Its benefits appear to have been offset by various adverse effects, mostly diseases and warfare.

The introduction of agriculture has not necessarily led to unequivocal progress. The nutritional standards of the growing Neolithic populations were inferior to that of hunter-gatherers. Several ethnological and archaeological studies conclude that the transition to cereal-based diets caused a reduction in life expectancy and stature, an increase in infant mortality and infectious diseases, the development of chronic, inflammatory or degenerative diseases (such as obesity, type 2 diabetes and cardiovascular diseases) and multiple nutritional deficiencies, including vitamin deficiencies, iron deficiency anemia and mineral disorders affecting bones (such as osteoporosis and rickets) and teeth. Average height went down from 5'10" (178 cm) for men and 5'6" (168 cm) for women to 5'5" (165 cm) and 5'1" (155 cm), respectively, and it took until the twentieth century for average human height to come back to the pre-Neolithic Revolution levels.

The traditional view is that agricultural food production supported a denser population, which in turn supported larger sedentary communities, the accumulation of goods and tools, and specialization in diverse forms of new labor. The development of larger societies led to the development of different means of decision making and to governmental organization. Food surpluses made possible the development of a social elite who were not otherwise engaged in agriculture, industry or commerce, but dominated their communities by other means and monopolized decision-making. Jared Diamond (in *The World Until Yesterday*) identifies the availability of milk and cereal grains as permitting mothers to raise both an older (e.g. 3 or 4 year old) and a younger child concurrently. The result is that a population can increase more rapidly. Diamond, in agreement with feminist scholars such as V. Spike Peterson, points out that agriculture brought about deep social divisions and encouraged gender inequality. This social reshuffle is traced by historical theorists, like Veronica Strang, through developments in theological depictions. Strang supports her theory through a comparison of aquatic deities before and after the Neolithic Agricultural Revolution, most notably the Venus of Lespugue and the Greco-Roman deities such as Circe or Charybdis: the former venerated and respected, the latter dominated and conquered. The theory, supplemented by the widely accepted assumption from Parsons that “society is always the object of religious veneration”, argues that with the centralization of government and the dawn of the Anthropocene, roles within society became more restrictive and were rationalized through the conditioning effect of religion; a process that is crystallized in the progression from polytheism to monotheism.

Subsequent revolutions

Andrew Sherratt has argued that following upon the Neolithic Revolution was a second phase of discovery that he refers to as the secondary products revolution. Animals, it appears, were first domesticated purely as a source of meat. The Secondary Products Revolution occurred when it was recognised that animals also provided a number of other useful products. These included:

- hides and skins (from undomesticated animals)
- manure for soil conditioning (from all domesticated animals)
- wool (from sheep, llamas, alpacas, and Angora goats)
- milk (from goats, cattle, yaks, sheep, horses, and camels)
- traction (from oxen, onagers, donkeys, horses, camels, and dogs)
- guarding and herding assistance (dogs)

Sherratt argued that this phase in agricultural development enabled humans to make use of the energy possibilities of their animals in new ways, and permitted permanent intensive subsistence farming and crop production, and the opening up of heavier soils for farming. It also made possible nomadic pastoralism in semi arid areas, along the margins of deserts, and eventually led to the domestication of both the dromedary and Bactrian camel. Overgrazing of these areas, particularly by herds of goats, greatly extended the areal extent of deserts.

Living in one spot permitted the accrual of personal possessions and an attachment to certain areas of land. From such a position, it is argued, prehistoric people were able to stockpile food to survive lean times and trade unwanted surpluses with others. Once trade and a secure food supply were established, populations could grow, and society could diversify into food producers and artisans, who could afford to develop their trade by virtue of the free time they enjoyed because of a surplus of food. The artisans, in turn, were able to develop technology such as metal weapons. Such relative complexity would have required some form of social organisation to work efficiently, so it is likely that populations that had such organisation, perhaps such as that provided by religion, were better prepared and more successful. In addition, the denser populations could form and support legions of professional soldiers. Also, during this time property ownership became increasingly important to all people. Ultimately, Childe argued that this growing social complexity, all rooted in the original decision to settle, led to a second Urban Revolution in which the first cities were built.

Diet and health

Compared to foragers, Neolithic farmers' diets were higher in carbohydrates but lower in fibre, micronutrients, and protein. This led to an increase in the frequency of carious teeth and slower growth in childhood and increased body fat, and studies have consistently found that populations around the world became shorter after the transition to agriculture. This trend may have been exacerbated by the greater seasonality of farming diets and with it the increased risk of famine due to crop failure.

Throughout the development of sedentary societies, disease spread more rapidly than it had during the time in which hunter-gatherer societies existed. Inadequate sanitary practices and the domestication of animals may explain the rise in deaths and sickness following the Neolithic Revolution, as diseases jumped from the animal to the human population. Some examples of infectious diseases spread from animals to humans are influenza, smallpox, and measles. Ancient microbial genomics has shown that progenitors to human-adapted strains of *Salmonella enterica* infected up to 5,500 year old agro-pastoralists throughout Western Eurasia, providing molecular evidence for the hypothesis that the Neolithization process facilitated the emergence of human-disease. In concordance with a process of natural selection, the humans who first domesticated the big mammals quickly built up immunities to the diseases as within each generation the individuals with better immunities had better chances of survival. In their approximately 10,000 years of shared proximity with animals, such as cows, Eurasians and Africans became more resistant to those diseases compared with the indigenous populations encountered outside Eurasia and Africa. For instance, the population of most Caribbean and several Pacific Islands have been completely wiped out by diseases. 90% or more of many populations of the Americas were wiped out by European and African diseases before recorded contact with European explorers or colonists. Some cultures like the Inca Empire did have a large domestic mammal, the llama, but llama milk was not drunk, nor did llamas live in a closed space with humans, so the risk of contagion was limited. According to bioarchaeological research, the effects of agriculture on physical and dental health in Southeast Asian rice farming societies from 4000 to 1500 BP was not detrimental to the same extent as in other world regions.

Jonathan C. K. Wells and Jay T. Stock have argued that the dietary changes and increased pathogen exposure associated with agriculture profoundly altered human biology and life history, creating conditions where natural selection favoured the allocation of resources towards reproduction over somatic effort.

Technology

In his book *Guns, Germs, and Steel*, Jared Diamond argues that Europeans and East Asians benefited from an advantageous geographical location that afforded them a head start in the Neolithic Revolution. Both shared the temperate climate ideal for the first agricultural settings, both were near a number of easily domesticable plant and animal species, and both were safer from attacks of other people than civilizations in the middle part of the Eurasian continent. Being among the first to adopt agriculture and sedentary lifestyles, and neighboring other early agricultural societies with whom they could compete and trade, both Europeans and East Asians were also among the first to benefit from technologies such as firearms and steel swords.

Archaeogenetics

The dispersal of Neolithic culture from the Middle East has recently been associated with the distribution of human genetic markers. In Europe, the spread of the Neolithic culture has been associated with distribution of the E1b1b lineages and Haplogroup J that are thought to have arrived in Europe from North Africa and the Near East respectively. In Africa, the spread of farming, and notably the Bantu expansion, is associated with the dispersal of Y-chromosome haplogroup E1b1a from West Africa. [unrelated Link]

Chapter 3

Ancient Egyptian Technology

Ancient Egyptian technology describes devices and technologies invented or used in Ancient Egypt. The Egyptians invented and used many simple machines, such as the ramp and the lever, to aid construction processes. They used rope trusses to stiffen the beam of ships. Egyptian paper, made from papyrus, and pottery were mass-produced and exported throughout the Mediterranean Basin. The wheel was used for a number of purposes, but chariots only came into use after the Second Intermediate Period. The Egyptians also played an important role in developing Mediterranean maritime technology including ships and lighthouses.

Technology in Dynastic Egypt

Significant advances in ancient Egypt during the dynastic period include astronomy, mathematics, and medicine. Their geometry was a necessary outgrowth of surveying to preserve the layout and ownership of fertile farmland, which was flooded annually by the Nile River. The 3,4,5 right triangle and other rules of thumb served to represent rectilinear structures, and the post and lintel architecture of Egypt. Egypt also was a center of alchemy research for much of the western world.

Paper, writing and libraries

The word *paper* comes from the Greek term for the ancient Egyptian writing material called papyrus, which was formed from beaten strips of papyrus plants. Papyrus was produced in Egypt as early as 3000 BC and was sold to ancient Greece and Rome. The establishment of the Library of Alexandria limited the supply of papyrus for others.

According to the Roman historian Pliny the Elder (*Natural History* records, xiii.21), as a result of this, parchment was invented under the patronage of Eumenes II of Pergamon to build his rival library at Pergamon. However, this is a myth; parchment had been in use in Anatolia and elsewhere long before the rise of Pergamon.

Egyptian hieroglyphs, a phonetic writing system, served as the basis for the Phoenician alphabet from which later alphabets, such as Hebrew, Greek, and Latin were derived. With this ability, writing and record-keeping, the Egyptians developed one of the – if not *the* – first decimal system.

The city of Alexandria retained preeminence for its records and scrolls with its library. This ancient library was damaged by fire when it fell under Roman rule, and was destroyed completely by 642 CE. With it, a vast supply of antique literature, history, and knowledge was lost.

Structures and construction

Materials and tools

Some of the older materials used in the construction of Egyptian housing included reeds and clay. According to Lucas and Harris, "reeds were plastered with clay in order to keep out of heat and cold more effectually". Tools that were used were "limestone, chiseled stones, wooden mallets, and stone hammers". With these tools, ancient Egyptians were able to create more than just housing, but also sculptures of their gods.

Buildings

Many Egyptian temples are not standing today. Some are in ruin from wear and tear, while others have been lost entirely. The Egyptian structures are among the largest constructions ever conceived and built by humans. They constitute one of the most potent and enduring symbols of ancient Egyptian civilization. Temples and tombs built by a pharaoh famous for her projects, Hatshepsut, were massive and included many colossal statues of her. Pharaoh Tutankamun's rock-cut tomb in the Valley of the Kings was full of jewelry and antiques. In some late myths, Ptah was identified as the primordial mound and had called creation into being, he was considered the deity of craftsmen, and in particular, of stone-based crafts. Imhotep, who was included in the Egyptian pantheon, was the first documented engineer.

In Hellenistic Egypt, lighthouse technology was developed, the most famous example being the Lighthouse of Alexandria. Alexandria was a port for the ships that traded the goods manufactured in Egypt or imported into Egypt. A giant cantilevered hoist lifted cargo to and from ships. The lighthouse itself was designed by Sostratus of Cnidus and built in the 3rd century BC (between 285 and 247 BC) on the island of Pharos in Alexandria, Egypt, which has since become a peninsula. This lighthouse was renowned in its time and knowledge of it was never lost. A 2006 drawing of it created from the study of many references, is shown at the right.

Monuments

- The Nile valley has been the site of one of the most influential civilizations in the world with its architectural monuments, which include the Giza pyramid complex and the Great Sphinx.

The most famous pyramids are the Egyptian pyramids—huge structures built of brick or stone, some of which are among the largest constructions by humans. Pyramids functioned as tombs for pharaohs.

In Ancient Egypt, a pyramid was referred to as *mer*, literally "place of ascendance." The Great Pyramid of Giza is the largest in Egypt and one of the largest in the world. The base is over 13 acres (53,000 m) in area. It is one of the Seven Wonders of the Ancient World and the only one of the seven to survive into modern times.

The ancient Egyptians capped the peaks of their pyramids with gold plated pyramidions and covered their faces with polished white limestone, although many of the stones used for the finishing purpose have fallen or been removed for use on other structures over the millennia.

The Red Pyramid (c.26th century BC), named for the light crimson hue of its exposed granite surfaces, is the third largest of Egyptian pyramids. Menkaure's Pyramid, likely dating to the same era, was constructed of limestone and granite blocks. The Great Pyramid of Giza (c. 2580 BC) contains a huge sarcophagus fashioned of red Aswan granite. The mostly ruined Black Pyramid dating from the reign of Amenemhat III once had a polished granite pyramidion or capstone, now on display in the main hall of the Egyptian Museum in Cairo. Other uses in Ancient Egypt include columns, door lintels, sills, jambs, and wall and floor veneer.

The ancient Egyptians had some of the first monumental stone buildings (such as in Saqqara). How the Egyptians worked the solid granite is still a matter of debate. Archaeologist Patrick Hunt has postulated that the Egyptians used emery shown to have higher hardness on the Mohs scale. Regarding construction, of the various methods possibly used by builders, the lever moved and uplifted obelisks weighing more than 100 tons.

Obelisks and pillars

Obelisks were a prominent part of the Ancient Egyptian architecture, placed in pairs at the entrances of various monuments and important buildings such as temples. In 1902, *Encyclopædia Britannica* wrote: "The earliest temple obelisk still in position is that of Senusret I of the XIIth Dynasty at Heliopolis (68 feet high)". The word *obelisk* is of Greek rather than Egyptian origin because Herodotus, the great traveler, was the first writer to describe the objects. Twenty-nine ancient Egyptian obelisks are known to have survived, plus the Unfinished obelisk being built by Hatshepsut to celebrate her sixteenth year as pharaoh. It broke while being carved out of the quarry and was abandoned when another one was begun to replace it. The broken one was found at Aswan and provides the only insight into the methods of how they were hewn.

The obelisk symbolized the sky deity Ra and during the brief religious reformation of Akhenaten was said to be a petrified ray of the Aten, the sun disk. It is hypothesized by New York University Egyptologist Patricia Blackwell Gary and *Astronomy* senior editor Richard Talcott that the shapes of the ancient Egyptian pyramid and obelisk were derived from natural phenomena associated with the sun (the sun-god Ra being the Egyptians' greatest deity). It was also thought that the deity existed within the structure. The Egyptians also used pillars extensively.

It is unknown whether the ancient Egyptians had kites, but a team led by Maureen Clemmons and Mory Gharib raised a 5,900-pound, 15-foot (4.6 m) obelisk into vertical position with a kite, a system of pulleys, and a support frame. Maureen Clemmons developed the idea that the ancient Egyptians used kites for work.

Ramps have been reported as being widely used in Ancient Egypt. A ramp is an inclined plane, or a plane surface set at an angle (other than a right angle) against a horizontal surface. The inclined plane permits one to overcome a large resistance by applying a relatively small force through a longer distance than the load is to be raised. In civil engineering the slope (ratio of rise/run) is often referred to as a grade or gradient. An inclined plane is one of the commonly-recognized simple machines. Maureen Clemmons subsequently led a team of researchers demonstrating a kite made of natural material and reinforced with shellac (which according to their research pulled with 97% the efficiency of nylon), in a 9 mph wind, would easily pull an average 2-ton pyramid stone up the 1st two courses of a pyramid (in collaboration with Cal Poly, Pomona, on a 53-stone pyramid built in Rosamond, CA).

Navigation and ship building

- The ancient Egyptians had knowledge to some extent of sail construction. This is governed by the science of aerodynamics. The earliest Egyptian sails were simply placed to catch the wind and push a vessel. Later Egyptian sails dating to 2400 BC were built with the recognition that ships could sail against the wind using the lift of the sails. Queen Hatshepsut oversaw the preparations and funding of an expedition of five ships, each measuring seventy feet long, and *with several sails*.Various others exist, also.

The ancient Egyptians had experience with building a variety of ships. Some of them survive to this day as Khufu ship. The ships were found in many areas of Egypt as the Abydos boats and remnants of other ships were found near the pyramids.

Sneferu's ancient cedar wood ship Praise of the Two Lands is the first reference recorded to a ship being referred to by name.

Although quarter rudders were the norm in Nile navigation, the Egyptians were the first to use also stern-mounted rudders (not of the modern type but center mounted steering oars).

The first warships of Ancient Egypt were constructed during the early Middle Kingdom and perhaps at the end of the Old Kingdom, but the first mention and a detailed description of a large enough and heavily armed ship dates from 16th century BC.

And I ordered to build twelve warships with rams, dedicated to Amun or Sobek, or Maat and Sekhmet, whose image was crowned best bronze noses. Carport and equipped outside rook over the waters, for many paddlers, having covered rowers deck not only from the side, but and top. and they were on board eighteen oars in two rows on the top and sat on two rowers, and the lower – one, a hundred and eight rowers were. And twelve rowers aft worked on three steering oars. And blocked Our Majesty ship inside three partitions (bulkheads) so as not to drown it by ramming the wicked, and the sailors had time to repair the hole. And Our Majesty arranged four towers for archers – two behind, and two on the nose and one above the other small – on the mast with narrow loopholes. they are covered with bronze in the fifth finger (3.2mm), as well as a canopy roof and its rowers. and they have (carried) on the nose three assault heavy crossbow arrows so they lit resin or oil with a salt of Seth (probably nitrate) tore a special blend and punched (?) lead ball with a lot of holes (?), and one of the same at the stern. and long ship seventy five cubits (41m), and the breadth sixteen, and in battle can go three-quarters of iteru per hour (about 6.5 knots)...

- *— The text of the tomb of Amenhotep I (KV39).*

When Thutmose III achieved warships displacement up to 360 tons and carried up to ten new heavy and light to seventeen catapults based bronze springs, called "siege crossbow" – more precisely, siege bows. Still appeared giant catamarans that are heavy warships and times of Ramesses III used even when the Ptolemaic dynasty.

According to the Greek historian Herodotus, Necho II sent out an expedition of Phoenicians, which reputedly, at some point between 610 and before 594 BC, sailed in three years from the Red Sea around Africa to the mouth of the Nile. Some Egyptologists dispute that an Egyptian pharaoh would authorize such an expedition, except for the reason of trade in the ancient maritime routes.

The belief in Herodotus' account, handed down to him by oral tradition, is primarily because he stated with disbelief that the Phoenicians "as they sailed on a westerly course round the southern end of Libya (Africa), they had the sun on their right – to northward of them" (*The Histories* 4.42) – in Herodotus' time it was not generally known that Africa was surrounded by an ocean (with the southern part of Africa being thought connected to Asia). So fantastic an assertion is this of a typical example of some seafarers' story and Herodotus therefore may never have mentioned it at all, had it not been based on facts and made with the according insistence.

This early description of Necho's expedition as a whole is contentious, though; it is recommended that one keep an open mind on the subject, but Strabo, Polybius, and Ptolemy doubted the description. Egyptologist A. B. Lloyd suggests that the Greeks at this time understood that anyone going south far enough and then turning west would have the Sun on their right but found it unbelievable that Africa reached so far south. He suggests that "It is extremely unlikely that an Egyptian king would, or could, have acted as Necho is depicted as doing" and that the story might have been triggered by the failure of Sataspes' attempt to circumnavigate Africa under Xerxes the Great. Regardless, it was believed by Herodotus and

Pliny. Much earlier, the Sea Peoples was a confederacy of seafaring raiders who sailed into the eastern shores of the Mediterranean, caused political unrest and attempted to enter or control Egyptian territory during the late 19th Dynasty, and especially during Year 8 of Ramesses III of the 20th Dynasty. The Egyptian Pharaoh Merneptah explicitly refers to them by the term "the foreign-countries (or 'peoples') of the sea" in his Great Karnak Inscription. Although some scholars believe that they "invaded" Cyprus and the Levant, this hypothesis is disputed.

Irrigation and agriculture

Irrigation as the artificial application of water to the soil was used to some extent in ancient Egypt, a hydraulic civilization (which entails hydraulic engineering). In crop production it is mainly used to replace missing rainfall in periods of drought, as opposed to reliance on direct rainfall (referred to as dryland farming or as rainfed farming). Before technology advanced, the people of Egypt relied on the natural flow of the Nile River to tend to the crops. Although the Nile provided sufficient watering survival domesticated animals, crops, and the people of Egypt, there were times where the Nile would flood the area wreaking havoc amongst the land. There is evidence of the ancient Egyptian pharaoh Amenemhet III in the Twelfth Dynasty (about 1800 BC) using the natural lake of the Fayûm as a reservoir to store surpluses of water for use during the dry seasons, as the lake swelled annually with the flooding of the Nile. Construction of drainage canals reduced the problems of major flooding from entering homes and areas of crops; but because it was a hydraulic civilization, much of the water management was controlled in a systematic way.

Glassworking

The earliest known glass beads from Egypt were made during the New Kingdom around 1500 BC and were produced in a variety of colors. They were made by winding molten glass around a metal bar and were highly prized as a trading commodity, especially blue beads, which were believed to have magical powers. The Egyptians made small jars and bottles using the core-formed method. Glass threads were wound around a bag of sand tied to a rod.

The glass was continually reheated to fuse the threads together. The glass-covered sand bag was kept in motion until the required shape and thickness was achieved. The rod was allowed to cool, then finally the bag was punctured and the sand poured out and reused . The Egyptians also created the first colored glass rods which they used to create colorful beads and decorations. They also worked with cast glass, which was produced by pouring molten glass into a mold, much like iron and the more modern crucible steel.

Astronomy

The Egyptians were a practical people and this is reflected in their astronomy in contrast to Babylonia where the first astronomical texts were written in astrological terms. Even before Upper and Lower Egypt were unified in 3000 BC, observations of the night sky had influenced the development of a religion in which many of its principal deities were heavenly bodies. In Lower Egypt, priests built circular mudbrick walls with which to make a false horizon where they could mark the position of the sun as it rose at dawn, and then with a plumb-bob note the northern or southern turning points (solstices). This allowed them to discover that the sun disc, personified as Ra, took 365 days to travel from his birthplace at the winter solstice and back to it. Meanwhile, in Upper Egypt, a lunar calendar was being developed based on the behavior of the moon and the reappearance of Sirius in its heliacal rising after its annual absence of about 70 days.

After unification, problems with trying to work with two calendars (both depending upon constant observation) led to a merged, simplified civil calendar with twelve 30-day months, three seasons of four months each, plus an extra five days, giving a 365-year day but with no way of accounting for the extra quarter day each year.

Day and night were split into 24 units, each personified by a deity. A sundial found on Seti I's cenotaph with instructions for its use shows us that the daylight hours were at one time split into 10 units, with 12 hours for the night and an hour for the morning and evening twilights.

However, by Seti I's time day and night were normally divided into 12 hours each, the length of which would vary according to the time of year.

Key to much of this was the motion of the sun god Ra and his annual movement along the horizon at sunrise. Out of Egyptian myths such as those around Ra and the sky goddess Nut came the development of the Egyptian calendar, time keeping, and even concepts of royalty. An astronomical ceiling in the burial chamber of Ramesses VI shows the sun being born from Nut in the morning, traveling along her body during the day and being swallowed at night.

During the Fifth Dynasty six kings built sun temples in honour of Ra. The temple complexes built by Niuserre at Abu Gurab and Userkaf at Abusir have been excavated and have astronomical alignments, and the roofs of some of the buildings could have been used by observers to view the stars, calculate the hours at night and predict the sunrise for religious festivals.

Claims have been made that precession of the equinoxes was known in ancient Egypt prior to the time of Hipparchus. This has been disputed however on the grounds that pre-Hipparchus texts do not mention precession and that "it is only by cunning interpretation of ancient myths and images, which are ostensibly about something else, that precession can be discerned in them, aided by some pretty esoteric numerological speculation involving the 72 years that mark one degree of shift in the zodiacal system and any number of permutations by multiplication, division, and addition."

Note however that the Egyptian observation of a slowly changing stellar alignment over a multi-year period does not necessarily mean that they understood or even cared what was going on.

For instance, from the Middle Kingdom onwards they used a table with entries for each month to tell the time of night from the passing of constellations.

These went in error after a few centuries because of their calendar and precession, but were copied (with scribal errors) long after they lost their practical usefulness or the possibility of understanding and use of them in the current years, rather than the years in which they were originally used.

Medicine

The Edwin Smith Papyrus is one of the first medical documents still extant, and perhaps the earliest document which attempts to describe and analyze the brain: given this, it might be seen as the very beginnings of neuroscience. However, medical historians believe that ancient Egyptian pharmacology was largely ineffective. According to a paper published by Michael D. Parkins, 72% of 260 medical prescriptions in the Hearst papyrus had no curative elements. According to Michael D. Parkins, sewage pharmacology first began in ancient Egypt and was continued through the Middle Ages, and while the use of animal dung can have curative properties, it is not without its risk. Practices such as applying cow dung to wounds, ear piercing, tattooing, and chronic ear infections were important factors in developing tetanus. Frank J. Snoek wrote that Egyptian medicine used fly specks, lizard blood, swine teeth, and other such remedies which he believes could have been harmful. Mummification of the dead was not always practiced in Egypt. Once the practice began, an individual was placed at a final resting place through a set of rituals and protocol. The Egyptian funeral was a complex ceremony including various monuments, prayers, and rituals undertaken in honor of the deceased. The poor, who could not afford expensive tombs, were buried in shallow graves in the sand, and because of the arid environment they were often naturally mummified.

The wheel

Evidence indicates that Egyptians made use of potter's wheels in the manufacturing of pottery from as early as the 4th Dynasty (c. 2613 to 2494 BC). Chariots, however, are only believed to have been introduced by the invasion of the Hyksos in the Second Intermediate Period (c.1650 BC to c.1550 BC); during the New Kingdom era (c.1550 BC to c.1077 BC), chariotry became central to Egypt's military.

Other developments

- The Egyptians developed a variety of furniture. There in the lands of ancient Egypt is the first evidence for stools, beds, and tables (such as from the tombs similar to Tutankhamun's). Recovered Ancient Egyptian furniture includes a third millennium BC bed discovered in the Tarkhan Tomb, a c.2550 BC. gilded set from the tomb of Queen Hetepheres I, and a c. 1550 BC. stool from Thebes.

Some have suggested that the Egyptians had some form of understanding electric phenomena from observing lightning and interacting with electric fish (such as *Malapterurus electricus*) or other animals (such as electric eels). The comment about lightning appears to come from a misunderstanding of a text referring to "high poles covered with copper plates" to argue this but Dr. Bolko Stern has written in detail explaining why the copper covered tops of poles (which were lower than the associated pylons) do not relate to electricity or lightning, pointing out that no evidence of anything used to manipulate electricity had been found in Egypt and that this was a magical and not a technical installation.

Those exploring fringe theories of ancient technology have suggested that there were electric lights used in Ancient Egypt.

Engineers have constructed a working model based on their interpretation of a relief found in the Hathor temple at the Dendera Temple complex. Authors (such as Peter Krassa and Reinhard Habeck) have produced a basic theory of the device's operation. The standard explanation, however, for the Dendera light, which comprises three stone reliefs (one single and a double representation) is that the depicted image represents a lotus leaf and flower from which a sacred snake is spawned in accordance with Egyptian mythological beliefs. This sacred snake sometimes is identified as the Milky Way (the snake) in the night sky (the leaf, lotus, or "bulb") that became identified with Hathor because of her similar association in creation.

Later technology in Egypt

Greco-Roman Egypt

Under Hellenistic rule, Egypt was one of the most prosperous regions of the Hellenistic civilization. The ancient Egyptian city of Rhakotis was renovated as Alexandria, which became the largest city around the Mediterranean Basin. Under Roman rule, Egypt was one of the most prosperous regions of the Roman Empire, with Alexandria being second only to ancient Rome in size.

Recent scholarship suggests that the water wheel originates from Ptolemaic Egypt, where it appeared by the 3rd century BC. This is seen as an evolution of the paddle-driven water-lifting wheels that had been known in Egypt a century earlier. According to John Peter Oleson, both the compartmented wheel and the hydraulic noria may have been invented in Egypt by the 4th century BC, with the Sakia being invented there a century later. This is supported by archeological finds at Faiyum, Egypt, where the oldest archeological evidence of a water-wheel has been found, in the form of a Sakia dating back to the 3rd century BC. A papyrus dating to the 2nd century BC also found in Faiyum mentions a water wheel used for irrigation, a 2nd-century BC fresco found at Alexandria depicts a compartmented Sakia, and the writings of Callixenus of Rhodes mention the use of a Sakia in Ptolemaic Egypt during the reign of Ptolemy IV in the late 3rd century BC. Ancient Greek technology was often inspired by the need to improve weapons and tactics in war. Ancient Roman technology is a set of artifacts and customs which supported Roman civilization and made the expansion of Roman commerce and Roman military possible over nearly a thousand years.

Arabic-Islamic Egypt

Under Arab rule, Egypt once again became one of the most prosperous regions around the Mediterranean. The Egyptian city of Cairo was founded by the Fatimid Caliphate and served as its capital city. At the time, Cairo was second only to Baghdad, capital of the rival Abbasid Caliphate. After the fall of Baghdad, however, Cairo overtook it as the largest city in the Mediterranean region until the early modern period.

Inventions in medieval Islam covers the inventions developed in the medieval Islamic world, a region that extended from Al-Andalus and Africa in the west to the Indian subcontinent and Central Asia in the east. The timeline of Islamic science and engineering covers the general development of science and technology in the Islamic world.

Chapter 4

Maya Civilization Technology

The Maya civilization (/ˈmaɪə/) was a Mesoamericancivilization developed by the Maya peoples, and noted for its logosyllabic script—the most sophisticated and highly developed writing system in pre-ColumbianAmericas—as well as for its art, architecture, mathematics, calendar, and astronomical system. The Maya civilization developed in the area that today comprises southeastern Mexico, all of Guatemala and Belize, and the western portions of Honduras and El Salvador. It includes the northern lowlands of the Yucatán Peninsula and the highlands of the Sierra Madre, the Mexican state of Chiapas, southern Guatemala, El Salvador, and the southern lowlands of the Pacific littoral plain. “Maya" is a modern term used to refer collectively to the various peoples that inhabited this area. They did not call themselves “Maya,” and did not have a sense of common identity or political unity. Today, their descendants, known collectively as the Maya, number well over 6 million individuals, speak more than twenty-eight surviving Mayan languages, and reside in nearly the same area as their ancestors.

The Archaic period, before 2000 BC, saw the first developments in agriculture and the earliest villages. The Preclassic period (c. 2000 BC to 250 AD) saw the establishment of the first complex societies in the Maya region, and the cultivation of the staple crops of the Maya diet, including maize, beans, squashes, and chili peppers. The first Maya cities developed around 750 BC, and by 500 BC these cities possessed monumental architecture, including large temples with elaborate stucco façades. Hieroglyphic writing was being used in the Maya region by the 3rd century BC. In the Late Preclassic a number of large cities developed in the Petén Basin, and the city of Kaminaljuyu rose to prominence in the Guatemalan Highlands. Beginning around 250 AD, the Classic period is largely defined as when the Maya were raising sculpted monuments with Long Count dates. This period saw the Maya civilization develop many city-states linked by a complex trade network. In the Maya Lowlands two great rivals, the cities of Tikal and Calakmul, became powerful. The Classic period also saw the intrusive intervention of the central Mexican city of Teotihuacan in Maya dynastic politics. In the 9th century, there was a widespread political collapse in the central Maya region, resulting in internecine warfare, the abandonment of cities, and a northward shift of population. The Postclassic period saw the rise of Chichen Itza in the north, and the expansion of the aggressive K'iche' kingdom in the Guatemalan Highlands. In the 16th century, the Spanish Empire colonised the Mesoamerican region, and a lengthy series of campaigns saw the fall of Nojpetén, the last Maya city, in 1697.

Rule during the Classic period centred on the concept of the "divine king", who was thought to act as a mediator between mortals and the supernatural realm. Kingship was patrilineal, and power normally passed to the eldest son. A prospective king was expected to be a successful war leader as well as a ruler. Closed patronage systems were the dominant force in Maya politics, although how patronage affected the political makeup of a kingdom varied from city-state to city-state. By the Late Classic period, the aristocracy had grown in size, reducing the previously exclusive power of the king. The Maya developed sophisticated art forms using both perishable and non-perishable materials, including wood, jade, obsidian, ceramics, sculpted stone monuments, stucco, and finely painted murals.

Maya cities tended to expand organically. The city centers comprised ceremonial and administrative complexes, surrounded by an irregularly shaped sprawl of residential districts. Different parts of a city were often linked by causeways. Architecturally, city buildings included palaces, pyramid-temples, ceremonial ballcourts, and structures specially aligned for astronomical observation. The Maya elite were literate, and developed a complex system of hieroglyphic writing. Theirs was the most advanced writing system in the pre-Columbian Americas. The Maya recorded their history and ritual knowledge in screenfold books, of which only three uncontested examples remain, the rest having been destroyed by the Spanish. In addition, a great many examples of Maya texts can be found on stelae and ceramics. The Maya developed a highly complex series of interlocking ritual calendars, and employed mathematics that included one of the earliest known instances of the explicit zero in human history. As a part of their religion, the Maya practised human sacrifice.

Mesoamerica

The Maya civilization developed within the Mesoamerican cultural area, which covers a region that spreads from northern Mexico southwards into Central America. Mesoamerica was one of six cradles of civilization worldwide. The Mesoamerican area gave rise to a series of cultural developments that included complex societies, agriculture, cities, monumental architecture, writing, and calendrical systems. The set of traits shared by Mesoamerican cultures also included astronomical knowledge, blood and human sacrifice, and a cosmovision that viewed the world as divided into four divisions aligned with the cardinal directions, each with different attributes, and a three-way division of the world into the celestial realm, the earth, and the underworld.

By 6000 BC, the early inhabitants of Mesoamerica were experimenting with the domestication of plants, a process that eventually led to the establishment of sedentaryagricultural societies. The diverse climate allowed for wide variation in available crops, but all regions of Mesoamerica cultivated the base crops of maize, beans, and squashes. All Mesoamerican cultures used Stone Age technology; after c. 1000 AD copper, silver and gold were worked. Mesoamerica lacked draft animals, did not use the wheel, and possessed few domesticated animals; the principal means of transport was on foot or by canoe. Mesoamericans viewed the world as hostile and governed by unpredictable deities. The ritual Mesoamerican ballgame was widely played. Mesoamerica is linguistically diverse, with most languages falling within a small number of language families—the major families are Mayan, Mixe–Zoquean, Otomanguean, and Uto-Aztecan; there are also a number of smaller families and isolates. The Mesoamerican language area shares a number of important features, including widespread loanwords, and use of a vigesimal number system.

The territory of the Maya covered a third of Mesoamerica, and the Maya were engaged in a dynamic relationship with neighbouring cultures that included the Olmecs, Mixtecs, Teotihuacan, the Aztecs, and others. During the Early Classic period, the Maya cities of Tikal and Kaminaljuyu were key Maya foci in a network that extended beyond the Maya area into the highlands of central Mexico. At around the same time, there was a strong Maya presence at the Tetitla compound of Teotihuacan. Centuries later, during the 9th century AD, murals at Cacaxtla, another site in the central Mexican highlands, were painted in a Maya style. This may have been either an effort to align itself with the still-powerful Maya area after the collapse of Teotihuacan and ensuing political fragmentation in the Mexican Highlands, or an attempt to express a distant Maya origin of the inhabitants. The Maya city of Chichen Itza and the distant Toltec capital of Tula had an especially close relationship.

Geography

The Maya civilization occupied a wide territory that included southeastern Mexico and northern Central America. This area included the entire Yucatán Peninsula and all of the territory now incorporated into the modern countries of Guatemala and Belize, as well as the western portions of Honduras and El Salvador. Most of the peninsula is formed by a vast plain with few hills or mountains and a generally low coastline.

The Petén region consists of densely forested low-lying limestone plain; a chain of fourteen lakes runs across the central drainage basin of Petén. To the south the plain gradually rises towards the Guatemalan Highlands. Dense forest covers northern Petén and Belize, most of Quintana Roo, southern Campeche, and a portion of the south of Yucatán state. Farther north, the vegetation turns to lower forest consisting of dense scrub.

The littoral zone of Soconusco lies to the south of the Sierra Madre de Chiapas, and consists of a narrow coastal plain and the foothills of the Sierra Madre. The Maya highlands extend eastwards from Chiapas into Guatemala, reaching their highest in the Sierra de los Cuchumatanes. The major pre-Columbian population centres of the highlands were located in the largest highland valleys, such as the Valley of Guatemala and the Quetzaltenango Valley. In the southern highlands, a belt of volcanic cones runs parallel to the Pacific coast. The highlands extend northwards into Verapaz, and gradually descend to the east.

History

- The history of Maya civilization is divided into three principal periods: the Preclassic, Classic, and Postclassic periods. These were preceded by the Archaic Period, during which the first settled villages and early developments in agriculture emerged. Modern scholars regard these periods as arbitrary divisions of Maya chronology, rather than indicative of cultural evolution or decline. Definitions of the start and end dates of period spans can vary by as much as a century, depending on the author.

Preclassic period (c. 2000 BC – 250 AD)

The Maya developed their first civilization in the Preclassic period. Scholars continue to discuss when this era of Maya civilization began. Maya occupation at Cuello (modern-day Belize) has been carbon dated to around 2600 BC. Settlements were established around 1800 BC in the Soconusco region of the Pacific coast, and the Maya were already cultivating the staple crops of maize, beans, squash, and chili pepper. This period was characterised by sedentary communities and the introduction of pottery and fired clay figurines.

A Lidar survey of the newly discovered Aguada Fénix site at Tabasco, Mexico uncovered large structures suggested to be a ceremonial site dating from between 1000 and 800 BC. The 2020 report of the survey, in the journal Nature, suggests its use as a ceremonial observation of the winter and summer solstices, with associated festivities and social gatherings.

During the Middle Preclassic Period, small villages began to grow to form cities. Nakbe in the Petén department of Guatemala is the earliest well-documented city in the Maya lowlands, where large structures have been dated to around 750 BC. The northern lowlands of Yucatán were widely settled by the Middle Preclassic. By approximately 400 BC, early Maya rulers were raising stelae. A developed script was already being used in Petén by the 3rd century BC. In the Late Preclassic Period, the enormous city of El Mirador grew to cover approximately 16 square kilometres (6.2 sq mi). Although not as large, Tikal was already a significant city by around 350 BC.

In the highlands, Kaminaljuyu emerged as a principal centre in the Late Preclassic. Takalik Abaj and Chocolá were two of the most important cities on the Pacific coastal plain, and Komchen grew to become an important site in northern Yucatán. The Late Preclassic cultural florescence collapsed in the 1st century AD and many of the great Maya cities of the epoch were abandoned; the cause of this collapse is unknown.

Classic period (c. 250–900 AD)

The Classic period is largely defined as the period during which the lowland Maya raised dated monuments using the Long Count calendar.

This period marked the peak of large-scale construction and urbanism, the recording of monumental inscriptions, and demonstrated significant intellectual and artistic development, particularly in the southern lowland regions.

The Classic period Maya political landscape has been likened to that of Renaissance Italy or Classical Greece, with multiple city-states engaged in a complex network of alliances and enmities. The largest cities had populations numbering 50,000 to 120,000 and were linked to networks of subsidiary sites.

During the Early Classic, cities throughout the Maya region were influenced by the great metropolis of Teotihuacan in the distant Valley of Mexico. In AD 378, Teotihuacan decisively intervened at Tikal and other nearby cities, deposed their rulers, and installed a new Teotihuacan-backed dynasty.

This intervention was led by Siyaj K’ak’ ("Born of Fire"), who arrived at Tikal in early 378. The king of Tikal, Chak Tok Ich’aak I, died on the same day, suggesting a violent takeover. A year later, Siyaj K’ak’ oversaw the installation of a new king, Yax Nuun Ahiin I. The installation of the new dynasty led to a period of political dominance when Tikal became the most powerful city in the central lowlands.

Tikal's great rival was Calakmul, another powerful city in the Petén Basin. Tikal and Calakmul both developed extensive systems of allies and vassals; lesser cities that entered one of these networks gained prestige from their association with the top-tier city, and maintained peaceful relations with other members of the same network. Tikal and Calakmul engaged in the manoeuvering of their alliance networks against each other. At various points during the Classic period, one or other of these powers would gain a strategic victory over its great rival, resulting in respective periods of florescence and decline.

In 629, B'alaj Chan K'awiil, a son of the Tikal king K'inich Muwaan Jol II, was sent to found a new city at Dos Pilas, in the Petexbatún region, apparently as an outpost to extend Tikal's power beyond the reach of Calakmul. For the next two decades he fought loyally for his brother and overlord at Tikal. In 648, kingYuknoom Ch'een II of Calakmul captured Balaj Chan K'awiil. Yuknoom Ch'een II then reinstated Balaj Chan K'awiil upon the throne of Dos Pilas as his vassal. He thereafter served as a loyal ally of Calakmul.

In the southeast, Copán was the most important city. Its Classic-period dynasty was founded in 426 by K'inich Yax K'uk' Mo'. The new king had strong ties with central Petén and Teotihuacan. Copán reached the height of its cultural and artistic development during the rule of Uaxaclajuun Ub'aah K'awiil, who ruled from 695 to 738. His reign ended catastrophically when he was captured by his vassal, king K'ak' Tiliw Chan Yopaat of Quiriguá. The captured lord of Copán was taken back to Quiriguá and was decapitated in a public ritual. It is likely that this coup was backed by Calakmul, in order to weaken a powerful ally of Tikal. Palenque and Yaxchilan were the most powerful cities in the Usumacinta region. In the highlands, Kaminaljuyu in the Valley of Guatemala was already a sprawling city by 300. In the north of the Maya area, Coba was the most important capital.

Classic Maya collapse

During the 9th century AD, the central Maya region suffered major political collapse, marked by the abandonment of cities, the ending of dynasties, and a northward shift in activity. No universally accepted theory explains this collapse, but it likely had a combination of causes, including endemic internecine warfare, overpopulation resulting in severe environmental degradation, and drought. During this period, known as the Terminal Classic, the northern cities of Chichen Itza and Uxmal showed increased activity. Major cities in the northern Yucatán Peninsula continued to be inhabited long after the cities of the southern lowlands ceased to raise monuments.

Classic Maya social organization was based on the ritual authority of the ruler, rather than central control of trade and food distribution. This model of rulership was poorly structured to respond to changes, because the ruler's actions were limited by tradition to such activities as construction, ritual, and warfare. This only served to exacerbate systemic problems. By the 9th and 10th centuries, this resulted in collapse of this system of rulership. In the northern Yucatán, individual rule was replaced by a ruling council formed from elite lineages. In the southern Yucatán and central Petén, kingdoms declined; in western Petén and some other areas, the changes were catastrophic and resulted in the rapid depopulation of cities. Within a couple of generations, large swathes of the central Maya area were all but abandoned. Both the capitals and their secondary centres were generally abandoned within a period of 50 to 100 years. One by one, cities stopped sculpting dated monuments; the last Long Count date was inscribed at Toniná in 909. Stelae were no longer raised, and squatters moved into abandoned royal palaces. Mesoamerican trade routes shifted and bypassed Petén.

Postclassic period (c. 950–1539 AD)

Although much reduced, a significant Maya presence remained into the Postclassic period after the abandonment of the major Classic period cities; the population was particularly concentrated near permanent water sources. Unlike during previous cycles of contraction in the Maya region, abandoned lands were not quickly resettled in the Postclassic. Activity shifted to the northern lowlands and the Maya Highlands; this may have involved migration from the southern lowlands, because many Postclassic Maya groups had migration myths. Chichen Itza and its Puuc neighbours declined dramatically in the 11th century, and this may represent the final episode of Classic Period collapse. After the decline of Chichen Itza, the Maya region lacked a dominant power until the rise of the city of Mayapan in the 12th century. New cities arose near the Caribbean and Gulf coasts, and new trade networks were formed.

The Postclassic Period was marked by changes from the preceding Classic Period. The once-great city of Kaminaljuyu in the Valley of Guatemala was abandoned after continuous occupation of almost 2,000 years. Across the highlands and neighbouring Pacific coast, long-occupied cities in exposed locations were relocated, apparently due to a proliferation of warfare. Cities came to occupy more-easily defended hilltop locations surrounded by deep ravines, with ditch-and-wall defences sometimes supplementing the protection provided by the natural terrain. One of the most important cities in the Guatemalan Highlands at this time was Q'umarkaj, the capital of the aggressive K'iche' kingdom. The government of Maya states, from the Yucatán to the Guatemalan highlands, was often organised as joint rule by a council. However, in practice one member of the council could act as a supreme ruler, while the other members served him as advisors.

Mayapan was abandoned around 1448, after a period of political, social and environmental turbulence that in many ways echoed the Classic period collapse in the southern Maya region. The abandonment of the city was followed by a period of prolonged warfare, disease and natural disasters in the Yucatán Peninsula, which ended only shortly before Spanish contact in 1511. Even without a dominant regional capital, the early Spanish explorers reported wealthy coastal cities and thriving marketplaces.

During the Late Postclassic, the Yucatán Peninsula was divided into a number of independent provinces that shared a common culture but varied in internal sociopolitical organization. On the eve of the Spanish conquest, the highlands of Guatemala were dominated by several powerful Maya states. The K'iche' had carved out a small empire covering a large part of the western Guatemalan Highlands and the neighbouring Pacific coastal plain. However, in the decades before the Spanish invasion the Kaqchikel kingdom had been steadily eroding the kingdom of the K'iche'.

Contact period and Spanish conquest (1511–1697 AD)

In 1511, a Spanish caravel was wrecked in the Caribbean, and about a dozen survivors made landfall on the coast of Yucatán. They were seized by a Maya lord, and most were sacrificed, although two managed to escape. From 1517 to 1519, three separate Spanish expeditions explored the Yucatán coast, and engaged in a number of battles with the Maya inhabitants. After the Aztec capital Tenochtitlan fell to the Spanish in 1521, Hernán Cortés despatched Pedro de Alvarado to Guatemala with 180 cavalry, 300 infantry, 4 cannons, and thousands of allied warriors from central Mexico; they arrived in Soconusco in 1523. The K'iche' capital, Q'umarkaj, fell to Alvarado in 1524. Shortly afterwards, the Spanish were invited as allies into Iximche, the capital city of the Kaqchikel Maya. Good relations did not last, due to excessive Spanish demands for gold as tribute, and the city was abandoned a few months later. This was followed by the fall of Zaculeu, the Mam Maya capital, in 1525. Francisco de Montejo and his son, Francisco de Montejo the Younger, launched a long series of campaigns against the polities of the Yucatán Peninsula in 1527, and finally completed the conquest of the northern portion of the peninsula in 1546. This left only the Maya kingdoms of the Petén Basin independent. In 1697, Martín de Ursúa launched an assault on the Itza capital Nojpetén and the last independent Maya city fell to the Spanish.

Persistence of Maya culture

The Spanish conquest stripped away most of the defining features of Maya civilization. However, many Maya villages remained remote from Spanish colonial authority, and for the most part continued to manage their own affairs. Maya communities and the nuclear family maintained their traditional day-to-day life. The basic Mesoamerican diet of maize and beans continued, although agricultural output was improved by the introduction of steel tools. Traditional crafts such as weaving, ceramics, and basketry continued to be practised.

Community markets and trade in local products continued long after the conquest. At times, the colonial administration encouraged the traditional economy in order to extract tribute in the form of ceramics or cotton textiles, although these were usually made to European specifications. Maya beliefs and language proved resistant to change, despite vigorous efforts by Catholic missionaries. The 260-day *tzolk'in* ritual calendar continues in use in modern Maya communities in the highlands of Guatemala and Chiapas, and millions of Mayan-language speakers inhabit the territory in which their ancestors developed their civilization.

Investigation of Maya civilization

The agents of the Catholic Church wrote detailed accounts of the Maya, in support of their efforts at Christianization, and absorption of the Maya into the Spanish Empire. This was followed by various Spanish priests and colonial officials who left descriptions of ruins they visited in Yucatán and Central America. In 1839, American traveller and writer John Lloyd Stephens set out to visit a number of Maya sites with English architect and draftsman Frederick Catherwood. Their illustrated accounts of the ruins sparked strong popular interest, and brought the Maya to the attention of the world.

The later 19th century saw the recording and recovery of ethnohistoric accounts of the Maya, and the first steps in deciphering Maya hieroglyphs.

The final two decades of the 19th century saw the birth of modern scientific archaeology in the Maya region, with the meticulous work of Alfred Maudslay and Teoberto Maler. By the early 20th century, the Peabody Museum was sponsoring excavations at Copán and in the Yucatán Peninsula. In the first two decades of the 20th century, advances were made in deciphering the Maya calendar, and identifying deities, dates, and religious concepts. Since the 1930s, archaeological exploration increased dramatically, with large-scale excavations across the Maya region.

In the 1960s, the distinguished Mayanist J. Eric S. Thompson promoted the ideas that Maya cities were essentially vacant ceremonial centres serving a dispersed population in the forest, and that the Maya civilization was governed by peaceful astronomer-priests. These ideas began to collapse with major advances in the decipherment of the script in the late 20th century, pioneered by Heinrich Berlin, Tatiana Proskouriakoff, and Yuri Knorozov. With breakthroughs in understanding of Maya script since the 1950s, the texts revealed the warlike activities of the Classic Maya kings, and the view of the Maya as peaceful could no longer be supported.

The capital of Sak Tz'i' (an Ancient Maya kingdom) now named Lacanja Tzeltal, was revealed by researchers led by associate anthropology professor Charles Golden and bioarchaeologist Andrew Scherer in Chiapas in the backyard of a Mexican farmer in 2020. Multiple domestic constructions used by the population for religious purposes. “Plaza Muk’ul Ton” or Monuments Plaza where people used to gather for ceremonies was also unearthed by the team.

The city will continue to be inspected and scanned by archaeologists under thick forest canopy using LIDAR technology (light detection and range) in June 2020.

Politics

Unlike the Aztecs and the Inca, the Maya political system never integrated the entire Maya cultural area into a single state or empire. Rather, throughout its history, the Maya area contained a varying mix of political complexity that included both states and chiefdoms. These polities fluctuated greatly in their relationships with each other and were engaged in a complex web of rivalries, periods of dominance or submission, vassalage, and alliances. At times, different polities achieved regional dominance, such as Calakmul, Caracol, Mayapan, and Tikal. The first reliably evidenced polities formed in the Maya lowlands in the 9th century BC.

During the Late Preclassic, the Maya political system coalesced into a theopolitical form, where elite ideology justified the ruler's authority, and was reinforced by public display, ritual, and religion. The divine king was the centre of political power, exercising ultimate control over the administrative, economic, judicial, and military functions of the polity. The divine authority invested within the ruler was such that the king was able to mobilize both the aristocracy and commoners in executing huge infrastructure projects, apparently with no police force or standing army. Some polities engaged in a strategy of increasing administration, and filling administrative posts with loyal supporters rather than blood relatives. Within a polity, mid-ranking population centres would have played a key role in managing resources and internal conflict.

The Maya political landscape was highly complex and Maya elites engaged in political intrigue to gain economic and social advantage over neighbours. In the Late Classic, some cities established a long period of dominance over other large cities, such as the dominance of Caracol over Naranjo for half a century. In other cases, loose alliance networks were formed around a dominant city. Border settlements, usually located about halfway between neighbouring capitals, often switched allegiance over the course of their history, and at times acted independently. Dominant capitals exacted tribute in the form of luxury items from subjugated population centres. Political power was reinforced by military power, and the capture and humiliation of enemy warriors played an important part in elite culture. An overriding sense of pride and honour among the warrior aristocracy could lead to extended feuds and vendettas, which caused political instability and the fragmentation of polities.

Society

From the Early Preclassic, Maya society was sharply divided between the elite and commoners. As population increased over time, various sectors of society became increasingly specialised, and political organization became increasingly complex. By the Late Classic, when populations had grown enormously and hundreds of cities were connected in a complex web of political hierarchies, the wealthy segment of society multiplied. A middle class may have developed that included artisans, low ranking priests and officials, merchants, and soldiers. Commoners included farmers, servants, labourers, and slaves. According to indigenous histories, land was held communally by noble houses or clans. Such clans held that the land was the property of the clan ancestors, and such ties between the land and the ancestors were reinforced by the burial of the dead within residential compounds.

King and court

Classic Maya rule was centred in a royal culture that was displayed in all areas of Classic Maya art. The king was the supreme ruler and held a semi-divine status that made him the mediator between the mortal realm and that of the gods. From very early times, kings were specifically identified with the young maize god, whose gift of maize was the basis of Mesoamerican civilization. Maya royal succession was patrilineal, and royal power only passed to queens when doing otherwise would result in the extinction of the dynasty. Typically, power was passed to the eldest son. A young prince was called a *ch'ok* ("youth"), although this word later came to refer to nobility in general. The royal heir was called *b'aah ch'ok* ("head youth"). Various points in the young prince's childhood were marked by ritual; the most important was a bloodletting ceremony at age five or six years. Although being of the royal bloodline was of utmost importance, the heir also had to be a successful war leader, as demonstrated by taking of captives. The enthronement of a new king was a highly elaborate ceremony, involving a series of separate acts that included enthronement upon a jaguar-skin cushion, human sacrifice, and receiving the symbols of royal power, such as a headband bearing a jade representation of the so-called "jester god", an elaborate headdress adorned with quetzal feathers, and a sceptre representing the god K'awiil.

Maya political administration, based around the royal court, was not bureaucratic in nature. Government was hierarchical, and official posts were sponsored by higher-ranking members of the aristocracy; officials tended to be promoted to higher levels of office during the course of their lives. Officials are referred to as being "owned" by their sponsor, and this relationship continued even after the death of the sponsor. The Maya royal court was a vibrant and dynamic political institution. There was no universal structure for the Maya royal court, instead each polity formed a royal court that was suited to its own individual context. A number of royal and noble titles have been identified by epigraphers translating Classic Maya inscriptions. *Ajaw* is usually translated as "lord" or "king". In the Early Classic, an *ajaw* was the ruler of a city. Later, with increasing social complexity, the *ajaw* was a member of the ruling class and a major city could have more than one, each ruling over different districts. Paramount rulers distinguished themselves from the extended nobility by prefixing the word *k'uhul* to their *ajaw* title. A *k'uhul ajaw* was "divine lord", originally confined to the kings of the most prestigious and ancient royal lines. *Kalomte* was a royal title, whose exact meaning is not yet deciphered, but it was held only by the most powerful kings of the strongest dynasties. It indicated an overlord, or high king, and the title was only in use during the Classic period. By the Late Classic, the absolute power of the *k'uhul ajaw* had weakened, and the political system had diversified to include a wider aristocracy, that by this time may well have expanded disproportionately.

A *sajal* was ranked below the *ajaw*, and indicated a subservient lord. A *sajal* would be lord of a second- or third-tier site, answering to an *ajaw*, who may himself have been subservient to a *kalomte*. A *sajal* would often be a war captain or regional governor, and inscriptions often link the *sajal* title to warfare; they are often mentioned as the holders of war captives. *Sajal* meant "feared one". The titles of *ah tz'ihb* and *ah ch'ul hun* are both related to scribes. The *ah tz'ihb* was a royal scribe, usually a member of the royal family; the *ah ch'ul hun* was the Keeper of the Holy Books, a title that is closely associated with the *ajaw* title, indicating that an *ajaw*always held the *ah ch'ul hun* title simultaneously. Other courtly titles, the functions of which are not well understood, were *yajaw k'ahk'* ("Lord of Fire"), *ti'huun* and *ti'sakhuun*.

These last two may be variations on the same title, and Mark Zender has suggested that the holder of this title may have been the spokesman for the ruler. Courtly titles are overwhelmingly male-oriented, and in those relatively rare occasions where they are applied to a woman, they appear to be used as honorifics for female royalty. Titled elites were often associated with particular structures in the hieroglyphic inscriptions of Classic period cities, indicating that such office holders either owned that structure, or that the structure was an important focus for their activities. A *lakam*, or standard-bearer, was possibly the only non-elite post-holder in the royal court. The *lakam* was only found in larger sites, and they appear to have been responsible for the taxation of local districts; one *lakam*, Apoch'Waal, was a diplomatic emissary for the *ajaw* of Calakmul, notable for establishing an alliance between Calakmul and Copán in 726.

Different factions may have existed in the royal court. The *k'uhul ahaw* and his household would have formed the central power-base, but other important groups were the priesthood, the warrior aristocracy, and other aristocratic courtiers. Where ruling councils existed, as at Chichen Itza and Copán, these may have formed an additional faction. Rivalry between different factions would have led to dynamic political institutions as compromises and disagreements were played out. In such a setting, public performance was vital. Such performances included ritual dances, presentation of war captives, offerings of tribute, human sacrifice, and religious ritual.

Commoners

Commoners are estimated to have comprised over 90% of the population, but relatively little is known about them. Their houses were generally constructed from perishable materials, and their remains have left little trace in the archaeological record. Some commoner dwellings were raised on low platforms, and these can be identified, but an unknown quantity of commoner houses were not. Such low-status dwellings can only be detected by extensive remote-sensing surveys of apparently empty terrain. The range of commoners was broad; it consisted of everyone not of noble birth, and therefore included everyone from the poorest farmers to wealthy craftsmen and commoners appointed to bureaucratic positions. Commoners engaged in essential production activities, including that of products destined for use by the elite, such as cotton and cacao, as well as subsistence crops for their own use, and utilitarian items such as ceramics and stone tools. Commoners took part in warfare, and could advance socially by proving themselves as outstanding warriors. Commoners paid taxes to the elite in the form of staple goods such as maize flour and game. It is likely that hard-working commoners who displayed exceptional skills and initiative could become influential members of Maya society.

Warfare

Warfare was prevalent in the Maya world. Military campaigns were launched for a variety of reasons, including the control of trade routes and tribute, raids to take captives, scaling up to the complete destruction of an enemy state. Little is known about Maya military organization, logistics, or training. Warfare is depicted in Maya art from the Classic period, and wars and victories are mentioned in hieroglyphic inscriptions. Unfortunately, the inscriptions do not provide information upon the causes of war, or the form it took.

In the 8th–9th centuries, intensive warfare resulted in the collapse of the kingdoms of the Petexbatún region of western Petén. The rapid abandonment of Aguateca by its inhabitants has provided a rare opportunity to examine the remains of Maya weaponry *in situ.* Aguateca was stormed by unknown enemies around 810 AD, who overcame its formidable defences and burned the royal palace. The elite inhabitants of the city either fled or were captured, and never returned to collect their abandoned property. The inhabitants of the periphery abandoned the site soon after. This is an example of intensive warfare carried out by an enemy in order to completely eliminate a Maya state, rather than subjugate it. Research at Aguateca indicated that Classic period warriors were primarily members of the elite.

From as early as the Preclassic period, the ruler of a Maya polity was expected to be a distinguished war leader, and was depicted with trophy heads hanging from his belt. In the Classic period, such trophy heads no longer appeared on the king's belt, but Classic period kings are frequently depicted standing over humiliated war captives. Right up to the end of the Postclassic period, Maya kings led as war captains. Maya inscriptions from the Classic show that a defeated king could be captured, tortured, and sacrificed. The Spanish recorded that Maya leaders kept track of troop movements in painted books.

The outcome of a successful military campaign could vary in its impact on the defeated polity. In some cases, entire cities were sacked, and never resettled, as at Aguateca. In other instances, the victors would seize the defeated rulers, their families, and patron gods. The captured nobles and their families could be imprisoned, or sacrificed. At the least severe end of the scale, the defeated polity would be obliged to pay tribute to the victor.

Warriors

During the Contact period, it is known that certain military positions were held by members of the aristocracy, and were passed on by patrilineal succession. It is likely that the specialised knowledge inherent in the particular military role was taught to the successor, including strategy, ritual, and war dances. Maya armies of the Contact period were highly disciplined, and warriors participated in regular training exercises and drills; every able-bodied adult male was available for military service. Maya states did not maintain standing armies; warriors were mustered by local officials who reported back to appointed warleaders. There were also units of full-time mercenaries who followed permanent leaders. Most warriors were not full-time, however, and were primarily farmers; the needs of their crops usually came before warfare. Maya warfare was not so much aimed at destruction of the enemy as the seizure of captives and plunder.

There is some evidence from the Classic period that women provided supporting roles in war, but they did not act as military officers with the exception of those rare ruling queens. By the Postclassic, the native chronicles suggest that women occasionally fought in battle.

Weapons

The *atlatl* (spear-thrower) was introduced to the Maya region by Teotihuacan in the Early Classic. This was a 0.5-metre-long (1.6 ft) stick with a notched end to hold a dart or javelin. The stick was used to launch the missile with more force and accuracy than could be accomplished by simply hurling it with the arm alone. Evidence in the form of stone blade points recovered from Aguateca indicate that darts and spears were the primary weapons of the Classic Maya warrior. Commoners used blowguns in war, which also served as their hunting weapon. The bow and arrow is another weapon that was used by the ancient Maya for both war and hunting. Although present in the Maya region during the Classic period, its use as a weapon of war was not favoured; it did not become a common weapon until the Postclassic. The Contact period Maya also used two-handed swords crafted from strong wood with the blade fashioned from inset obsidian, similar to the Aztec *macuahuitl*. Maya warriors wore body armour in the form of quilted cotton that had been soaked in salt water to toughen it; the resulting armour compared favourably to the steel armour worn by the Spanish when they conquered the region. Warriors bore wooden or animal hide shields decorated with feathers and animal skins.

Trade

Trade was a key component of Maya society, and in the development of the Maya civilization. The cities that grew to become the most important usually controlled access to vital trade goods, or portage routes. Cities such as Kaminaljuyu and Q'umarkaj in the Guatemalan Highlands, and Chalchuapa in El Salvador, variously controlled access to the sources of obsidian at different points in Maya history. The Maya were major producers of cotton, which was used to make the textiles to be traded throughout Mesoamerica. The most important cities in the northern Yucatán Peninsula controlled access to the sources of salt. In the Postclassic, the Maya engaged in a flourishing slave trade with wider Mesoamerica.

The Maya engaged in long distance trade across the Maya region, and across greater Mesoamerica and beyond. As an illustration, an Early Classic Maya merchant quarter has been identified at the distant metropolis of Teotihuacan, in central Mexico. Within Mesoamerica beyond the Maya area, trade routes particularly focused on central Mexico and the Gulf coast. In the Early Classic, Chichen Itza was at the hub of an extensive trade network that imported gold discs from Colombia and Panama, and turquoise from Los Cerrillos, New Mexico. Long-distance trade of both luxury and utilitarian goods was probably controlled by the royal family. Prestige goods obtained by trade were used both for consumption by the city's ruler, and as luxury gifts to consolidate the loyalty of vassals and allies.

Trade routes not only supplied physical goods, they facilitated the movement of people and ideas throughout Mesoamerica. Shifts in trade routes occurred with the rise and fall of important cities in the Maya region, and have been identified in every major reorganization of the Maya civilization, such as the rise of Preclassic Maya civilization, the transition to the Classic, and the Terminal Classic collapse. Even the Spanish Conquest did not immediately terminate all Maya trading activity; for example, the Contact period Manche Ch’ol traded the prestige crops of cacao, annatto and vanilla into colonial Verapaz.

Merchants

Little is known of Maya merchants, although they are depicted on Maya ceramics in elaborate noble dress. From this, it is known that at least some traders were members of the elite. During the Contact period, it is known that Maya nobility took part in long-distance trading expeditions. The majority of traders were middle class, but were largely engaged in local and regional trade rather than the prestigious long distance trading that was the preserve of the elite. The travelling of merchants into dangerous foreign territory was likened to a passage through the underworld; the patron deities of merchants were two underworld gods carrying backpacks. When merchants travelled, they painted themselves black, like their patron gods, and went heavily armed.

The Maya had no pack animals, so all trade goods were carried on the backs of porters when going overland; if the trade route followed a river or the coast, then goods were transported in canoes. A substantial Maya trading canoe was encountered off Honduras on Christopher Columbus's fourth voyage. It was made from a large hollowed-out tree trunk and had a palm-covered canopy. The canoe was 2.5 metres (8.2 ft) broad and was powered by 25 rowers. Trade goods carried included cacao, obsidian, ceramics, textiles, food and drink for the crew, and copper bells and axes. Cacao was used as currency (although not exclusively), and its value was such that counterfeiting occurred by removing the flesh from the pod, and stuffing it with dirt or avocado rind.

Marketplaces

Marketplaces are difficult to identify archaeologically. However, the Spanish reported a thriving market economy when they arrived in the region. At some Classic period cities, archaeologists have tentatively identified formal arcade-style masonry architecture and parallel alignments of scattered stones as the permanent foundations of market stalls. A 2007 study analysed soils from a modern Guatemalan market and compared the results with those obtained from analysis at a proposed ancient market at Chunchucmil. Unusually high levels of zinc and phosphorus at both sites indicated similar food production and vegetable sales activity. The calculated density of market stalls at Chunchucmil strongly suggests that a thriving market economy already existed in the Early Classic. Archaeologists have tentatively identified marketplaces at an increasing number of Maya cities by means of a combination of archaeology and soil analysis. When the Spanish arrived, Postclassic cities in the highlands had markets in permanent plazas, with officials on hand to settle disputes, enforce rules, and collect taxes.

Art

Maya art is essentially the art of the royal court. It is almost exclusively concerned with the Maya elite and their world. Maya art was crafted from both perishable and non-perishable materials, and served to link the Maya to their ancestors. Although surviving Maya art represents only a small proportion of the art that the Maya created, it represents a wider variety of subjects than any other art tradition in the Americas. Maya art has many regional styles, and is unique in the ancient Americas in bearing narrative text. The finest surviving Maya art dates to the Late Classic period.

The Maya exhibited a preference for the colour green or blue-green, and used the same word for the colours blue and green. Correspondingly, they placed high value on apple-green jade, and other greenstones, associating them with the sun-god K'inich Ajau. They sculpted artefacts that included fine tesserae and beads, to carved heads weighing 4.42 kilograms (9.7 lb). The Maya nobility practised dental modification, and some lords wore encrusted jade in their teeth. Mosaic funerary masks could also be fashioned from jade, such as that of K'inich Janaab' Pakal, king of Palenque.

Maya stone sculpture emerged into the archaeological record as a fully developed tradition, suggesting that it may have evolved from a tradition of sculpting wood. Because of the biodegradability of wood, the corpus of Maya woodwork has almost entirely disappeared. The few wooden artefacts that have survived include three-dimensional sculptures, and hieroglyphic panels. Stone Maya stelae are widespread in city sites, often paired with low, circular stones referred to as altars in the literature. Stone sculpture also took other forms, such as the limestone relief panels at Palenque and Piedras Negras. At Yaxchilan, Dos Pilas, Copán, and other sites, stone stairways were decorated with sculpture. The hieroglyphic stairway at Copán comprises the longest surviving Maya hieroglyphic text, and consists of 2,200 individual glyphs.

The largest Maya sculptures consisted of architectural façades crafted from stucco. The rough form was laid out on a plain plaster base coating on the wall, and the three-dimensional form was built up using small stones. Finally, this was coated with stucco and moulded into the finished form; human body forms were first modelled in stucco, with their costumes added afterwards. The final stucco sculpture was then brightly painted. Giant stucco masks were used to adorn temple façades by the Late Preclassic, and such decoration continued into the Classic period.

The Maya had a long tradition of mural painting; rich polychrome murals have been excavated at San Bartolo, dating to between 300 and 200 BC. Walls were coated with plaster, and polychrome designs were painted onto the smooth finish. The majority of such murals have not survived, but Early Classic tombs painted in cream, red, and black have been excavated at Caracol, Río Azul, and Tikal. Among the best preserved murals are a full-size series of Late Classic paintings at Bonampak.

Flint, chert, and obsidian all served utilitarian purposes in Maya culture, but many pieces were finely crafted into forms that were never intended to be used as tools. Eccentric flints are among the finest lithic artefacts produced by the ancient Maya. They were technically very challenging to produce, requiring considerable skill on the part of the artisan. Large obsidian eccentrics can measure over 30 centimetres (12 in) in length. Their actual form varies considerably but they generally depict human, animal and geometric forms associated with Maya religion. Eccentric flints show a great variety of forms, such as crescents, crosses, snakes, and scorpions. The largest and most elaborate examples display multiple human heads, with minor heads sometimes branching off from larger one.

Maya textiles are very poorly represented in the archaeological record, although by comparison with other pre-Columbian cultures, such as the Aztecs and the Andean region, it is likely that they were high-value items. A few scraps of textile have been recovered by archaeologists, but the best evidence for textile art is where they are represented in other media, such as painted murals or ceramics. Such secondary representations show the elite of the Maya court adorned with sumptuous cloths, generally these would have been cotton, but jaguar pelts and deer hides are also shown.

Ceramics are the most commonly surviving type of Maya art. The Maya had no knowledge of the potter's wheel, and Maya vessels were built up by coiling rolled strips of clay into the desired form. Maya pottery was not glazed, although it often had a fine finish produced by burnishing. Maya ceramics were painted with clay slips blended with minerals and coloured clays. Ancient Maya firing techniques have yet to be replicated. A quantity of extremely fine ceramic figurines have been excavated from Late Classic tombs on Jaina Island, in northern Yucatán. They stand from 10 to 25 centimetres (3.9 to 9.8 in) high and were hand modelled, with exquisite detail. The *Ik*-style polychrome ceramic corpus, including finely painted plates and cylindrical vessels, originated in Late Classic Motul de San José. It includes a set of features such as hieroglyphs painted in a pink or pale red colour and scenes with dancers wearing masks. One of the most distinctive features is the realistic representation of subjects as they appeared in life. The subject matter of the vessels includes courtly life from the Petén region in the 8th century AD, such as diplomatic meetings, feasting, bloodletting, scenes of warriors and the sacrifice of prisoners of war.

Bone, both human and animal, was also sculpted; human bones may have been trophies, or relics of ancestors. The Maya valued Spondylus shells, and worked them to remove the white exterior and spines, to reveal the fine orange interior. Around the 10th century AD, metallurgy arrived in Mesoamerica from South America, and the Maya began to make small objects in gold, silver and copper. The Maya generally hammered sheet metal into objects such as beads, bells, and discs. In the last centuries before the Spanish Conquest, the Maya began to use the lost-wax method to cast small metal pieces.

One poorly studied area of Maya folk art is graffiti. Additional graffiti, not part of the planned decoration, was incised into the stucco of interior walls, floors, and benches, in a wide variety of buildings, including temples, residences, and storerooms. Graffiti has been recorded at 51 Maya sites, particularly clustered in the Petén Basin and southern Campeche, and the Chenes region of northwestern Yucatán. At Tikal, where a great quantity of graffiti has been recorded, the subject matter includes drawings of temples, people, deities, animals, banners, litters, and thrones. Graffiti was often inscribed haphazardly, with drawings overlapping each other, and display a mix of crude, untrained art, and examples by artists who were familiar with Classic-period artistic conventions.

Architecture

The Maya produced a vast array of structures, and have left an extensive architectural legacy. Maya architecture also incorporates various art forms and hieroglyphic texts. Masonry architecture built by the Maya evidences craft specialization in Maya society, centralised organization and the political means to mobilize a large workforce. It is estimated that a large elite residence at Copán required an estimated 10,686 man-days to build, which compares to 67-man-days for a commoner's hut. It is further estimated that 65% of the labour required to build the noble residence was used in the quarrying, transporting, and finishing of the stone used in construction, and 24% of the labour was required for the manufacture and application of limestone-based plaster. Altogether, it is estimated that two to three months were required for the construction of the residence for this single noble at Copán, using between 80 and 130 full-time labourers. A Classic-period city like Tikal was spread over 20 square kilometres (7.7 sq mi), with an urban core covering 6 square kilometres (2.3 sq mi). The labour required to build such a city was immense, running into many millions of man-days. The most massive structures ever erected by the Maya were built during the Preclassic period. Craft specialization would have required dedicated stonemasons and plasterers by the Late Preclassic, and would have required planners and architects.

Urban design

Maya cities were not formally planned, and were subject to irregular expansion, with the haphazard addition of palaces, temples and other buildings. Most Maya cities tended to grow outwards from the core, and upwards as new structures were superimposed upon preceding architecture. Maya cities usually had a ceremonial and administrative centre surrounded by a vast irregular sprawl of residential complexes. The centres of all Maya cities featured sacred precincts, sometimes separated from nearby residential areas by walls. These precincts contained pyramid temples and other monumental architecture dedicated to elite activities, such as basal platforms that supported administrative or elite residential complexes. Sculpted monuments were raised to record the deeds of the ruling dynasty. City centres also featured plazas, sacred ballcourts and buildings used for marketplaces and schools. Frequently causeways linked the centre to outlying areas of the city. Some of these classes of architecture formed lesser groups in the outlying areas of the city, which served as sacred centres for non-royal lineages. The areas adjacent to these sacred compounds included residential complexes housing wealthy lineages. The largest and richest of these elite compounds sometimes possessed sculpture and art of craftsmanship equal to that of royal art.

The ceremonial centre of the Maya city was where the ruling elite lived, and where the administrative functions of the city were performed, together with religious ceremonies. It was also where the inhabitants of the city gathered for public activities. Elite residential complexes occupied the best land around the city centre, while commoners had their residences dispersed further away from the ceremonial centre. Residential units were built on top of stone platforms to raise them above the level of the rain season floodwaters.

Building materials and methods

The Maya built their cities with Neolithic technology; they built their structures from both perishable materials and from stone. The exact type of stone used in masonry construction varied according to locally available resources, and this also affected the building style. Across a broad swathe of the Maya area, limestone was immediately available.

The local limestone is relatively soft when freshly cut, but hardens with exposure. There was great variety in the quality of limestone, with good-quality stone available in the Usumacinta region; in the northern Yucatán, the limestone used in construction was of relatively poor quality. Volcanic tuff was used at Copán, and nearby Quiriguá employed sandstone. In Comalcalco, where suitable stone was not available locally, fired bricks were employed. Limestone was burned at high temperatures in order to manufacture cement, plaster, and stucco. Lime-based cement was used to seal stonework in place, and stone blocks were fashioned using rope-and-water abrasion, and with obsidian tools. The Maya did not employ a functional wheel, so all loads were transported on litters, barges, or rolled on logs. Heavy loads were lifted with rope, but probably without employing pulleys.

Wood was used for beams, and for lintels, even in masonry structures. Throughout Maya history, common huts and some temples continued to be built from wooden poles and thatch. Adobe was also applied; this consisted of mud strengthened with straw and was applied as a coating over the woven-stick walls of huts. Like wood and thatch, adobe was used throughout Maya history, even after the development of masonry structures. In the southern Maya area, adobe was employed in monumental architecture when no suitable stone was locally available.

Principal construction types

The great cities of the Maya civilization were composed of pyramid temples, palaces, ballcourts, *sacbeob* (causeways), patios and plazas. Some cities also possessed extensive hydraulic systems or defensive walls. The exteriors of most buildings were painted, either in one or multiple colours, or with imagery. Many buildings were adorned with sculpture or painted stucco reliefs.

Palaces and acropoleis

These complexes were usually located in the site core, beside a principal plaza. Maya palaces consisted of a platform supporting a multiroom range structure. The term *acropolis*, in a Maya context, refers to a complex of structures built upon platforms of varying height. Palaces and acropoleis were essentially elite residential compounds. They generally extended horizontally as opposed to the towering Maya pyramids, and often had restricted access. Some structures in Maya acropoleis supported roof combs. Rooms often had stone benches, used for sleeping, and holes indicate where curtains once hung. Large palaces, such as at Palenque, could be fitted with a water supply, and sweat baths were often found within the complex, or nearby. During the Early Classic, rulers were sometimes buried underneath the acropolis complex. Some rooms in palaces were true throne rooms; in the royal palace of Palenque there were a number of throne rooms that were used for important events, including the inauguration of new kings.

Palaces are usually arranged around one or more courtyards, with their façades facing inwards; some examples are adorned with sculpture. Some palaces possess associated hieroglyphic descriptions that identify them as the royal residences of named rulers. There is abundant evidence that palaces were far more than simple elite residences, and that a range of courtly activities took place in them, including audiences, formal receptions, and important rituals.

Pyramids and temples

Temples were sometimes referred to in hieroglyphic texts as *k'uh nah*, meaning "god's house". Temples were raised on platforms, most often upon a pyramid. The earliest temples were probably thatched huts built upon low platforms. By the Late Preclassic period, their walls were of stone, and the development of the corbel arch allowed stone roofs to replace thatch. By the Classic period, temple roofs were being topped with roof combs that extended the height of the temple and served as a foundation for monumental art. The temple shrines contained between one and three rooms, and were dedicated to important deities. Such a deity might be one of the patron gods of the city, or a deified ancestor. In general, freestanding pyramids were shrines honouring powerful ancestors.

E-Groups and observatories

The Maya were keen observers of the sun, stars, and planets. E-Groups were a particular arrangement of temples that were relatively common in the Maya region; they take their names from Group E at Uaxactun. They consisted of three small structures facing a fourth structure, and were used to mark the solstices and equinoxes.

The earliest examples date to the Preclassic period. The Lost World complex at Tikal started out as an E-Group built towards the end of the Middle Preclassic. Due to its nature, the basic layout of an E-Group was constant. A structure was built on the west side of a plaza; it was usually a radial pyramid with stairways facing the cardinal directions. It faced east across the plaza to three small temples on the far side. From the west pyramid, the sun was seen to rise over these temples on the solstices and equinoxes. E-Groups were raised across the central and southern Maya area for over a millennium; not all were properly aligned as observatories, and their function may have been symbolic.

As well as E-Groups, the Maya built other structures dedicated to observing the movements of celestial bodies. Many Maya buildings were aligned with astronomical bodies, including the planet Venus, and various constellations. The Caracol structure at Chichen Itza was a circular multi-level edifice, with a conical superstructure. It has slit windows that marked the movements of Venus. At Copán, a pair of stelae were raised to mark the position of the setting sun at the equinoxes.

Triadic pyramids

Triadic pyramids first appeared in the Preclassic. They consisted of a dominant structure flanked by two smaller inward-facing buildings, all mounted upon a single basal platform. The largest known triadic pyramid was built at El Mirador in the Petén Basin; it covers an area six times as large as that covered by Temple IV, the largest pyramid at Tikal. The three superstructures all have stairways leading up from the central plaza on top of the basal platform. No securely established forerunners of Triadic Groups are known, but they may have developed from the eastern range building of E-Group complexes.

The triadic form was the predominant architectural form in the Petén region during the Late Preclassic. Examples of triadic pyramids are known from as many as 88 archaeological sites. At Nakbe, there are at least a dozen examples of triadic complexes and the four largest structures in the city are triadic in nature. At El Mirador there are probably as many as 36 triadic structures. Examples of the triadic form are even known from Dzibilchaltun in the far north of the Yucatán Peninsula, and Q’umarkaj in the Highlands of Guatemala. The triadic pyramid remained a popular architectural form for centuries after the first examples were built; it continued in use into the Classic Period, with later examples being found at Uaxactun, Caracol, Seibal, Nakum, Tikal and Palenque. The Q’umarkaj example is the only one that has been dated to the

Postclassic Period. The triple-temple form of the triadic pyramid appears to be related to Maya mythology.

Ballcourts

The ballcourt is a distinctive pan-Mesoamerican form of architecture. Although the majority of Maya ballcourts date to the Classic period, the earliest examples appeared around 1000 BC in northwestern Yucatán, during the Middle Preclassic. By the time of Spanish contact, ballcourts were only in use in the Guatemalan Highlands, at cities such as Q'umarkaj and Iximche. Throughout Maya history, ballcourts maintained a characteristic form consisting of anı shape, with a central playing area terminating in two transverse end zones. The central playing area usually measures between 20 and 30 metres (66 and 98 ft) long, and is flanked by two lateral structures that stood up to 3 or 4 metres (9.8 or 13.1 ft) high.

The lateral platforms often supported structures that may have held privileged spectators. The Great Ballcourt at Chichen Itza is the largest in Mesoamerica, measuring 83 metres (272 ft) long by 30 metres (98 ft) wide, with walls standing 8.2 metres (27 ft) high.

Regional architectural styles

Although Maya cities shared many common features, there was considerable variation in architectural style. Such styles were influenced by locally available construction materials, climate, topography, and local preferences. In the Late Classic, these local differences developed into distinctive regional architectural styles.

Central Petén

The central Petén style of architecture is modelled after the great city of Tikal. The style is characterised by tall pyramids supporting a summit shrine adorned with a roof comb, and accessed by a single doorway.

Additional features are the use of stela-altar pairings, and the decoration of architectural façades, lintels, and roof combs with relief sculptures of rulers and gods. One of the finest examples of Central Petén style architecture is Tikal Temple I. Examples of sites in the Central Petén style include Altun Ha, Calakmul, Holmul, Ixkun, Nakum, Naranjo, and Yaxhá.

Puuc

The exemplar of Puuc-style architecture is Uxmal. The style developed in the Puuc Hills of northwestern Yucatán; during the Terminal Classic it spread beyond this core region across the northern Yucatán Peninsula. Puuc sites replaced rubble cores with lime cement, resulting in stronger walls, and also strengthened their corbel arches; this allowed Puuc-style cities to build freestanding entrance archways.

The upper façades of buildings were decorated with precut stones mosaic-fashion, erected as facing over the core, forming elaborate compositions of long-nosed deities such as the rain god Chaac and the Principal Bird Deity. The motifs also included geometric patterns, lattices and spools, possibly influenced by styles from highland Oaxaca, outside the Maya area. In contrast, the lower façades were left undecorated. Roof combs were relatively uncommon at Puuc sites.

Chenes

The Chenes style is very similar to the Puuc style, but predates the use of the mosaic façades of the Puuc region. It featured fully adorned façades on both the upper and lower sections of structures. Some doorways were surrounded by mosaic masks of monsters representing mountain or sky deities, identifying the doorways as entrances to the supernatural realm. Some buildings contained interior stairways that accessed different levels. The Chenes style is most commonly encountered in the southern portion of the Yucatán Peninsula, although individual buildings in the style can be found elsewhere in the peninsula. Examples of Chenes sites include Dzibilnocac, Hochob, Santa Rosa Xtampak, and Tabasqueño.

Río Bec

The Río Bec style forms a sub-region of the Chenes style, and also features elements of the Central Petén style, such as prominent roof combs. Its palaces are distinctive for their false-tower decorations, lacking interior rooms, with steep, almost vertical, stairways and false doors. These towers were adorned with deity masks, and were built to impress the viewer, rather than serve any practical function. Such false towers are only found in the Río Bec region. Río Bec sites include Chicanná, Hormiguero, and Xpuhil.

Usumacinta

The Usumacinta style developed in the hilly terrain of the Usumacinta drainage. Cities took advantage of the hillsides to support their major architecture, as at Palenque and

Yaxchilan. Sites modified corbel vaulting to allow thinner walls and multiple access doors to temples. As in Petén, roof combs adorned principal structures. Palaces had multiple entrances that used post-and-lintel entrances rather than corbel vaulting. Many sites erected stelae, but Palenque instead developed finely sculpted panelling to decorate its buildings.

Language

Before 2000 BC, the Maya spoke a single language, dubbed proto-Mayan by linguists. Linguistic analysis of reconstructed Proto-Mayan vocabulary suggests that the original Proto-Mayan homeland was in the western or northern Guatemalan Highlands, although the evidence is not conclusive.

Proto-Mayan diverged during the Preclassic period to form the major Mayan language groups that make up the family, including Huastecan, Greater K'iche'an, Greater Q'anjobalan, Mamean, Tz'eltalan-Ch'olan, and Yucatecan. These groups diverged further during the pre-Columbian era to form over 30 languages that have survived into modern times.

The language of almost all Classic Maya texts over the entire Maya area has been identified as Ch'olan; Late Preclassic text from Kaminaljuyu, in the highlands, also appears to be in, or related to, Ch'olan.

The use of Ch'olan as the language of Maya text does not necessarily indicate that it was the language commonly used by the local populace – it may have been equivalent to Medieval Latin as a ritual or prestige language. Classic Ch'olan may have been the prestige language of the Classic Maya elite, used in inter-polity communication such as diplomacy and trade. By the Postclassic period, Yucatec was also being written in Maya codices alongside Ch'olan.

Writing and literacy

The Maya writing system is one of the outstanding achievements of the pre-Columbian inhabitants of the Americas. It was the most sophisticated and highly developed writing system of more than a dozen systems that developed in Mesoamerica. The earliest inscriptions in an identifiably Maya script date back to 300–200 BC, in the Petén Basin. However, this is preceded by several other Mesoamerican writing systems, such as the Epi-Olmec and Zapotec scripts. Early Maya script had appeared on the Pacific coast of Guatemala by the late 1st century AD, or early 2nd century. Similarities between the Isthmian script and Early Maya script of the Pacific coast suggest that the two systems developed in tandem. By about AD 250, the Maya script had become a more formalised and consistent writing system.

The Catholic Church and colonial officials, notably Bishop Diego de Landa, destroyed Maya texts wherever they found them, and with them the knowledge of Maya writing, but by chance three uncontested pre-Columbian books dated to the Postclassic period have been preserved. These are known as the *Madrid Codex*, the *Dresden Codex* and the *Paris Codex*. A few pages survive from a fourth, the *Grolier Codex*, whose authenticity is disputed. Archaeology conducted at Maya sites often reveals other fragments, rectangular lumps of plaster and paint chips which were codices; these tantalizing remains are, however, too severely damaged for any inscriptions to have survived, most of the organic material having decayed. In reference to the few extant Maya writings, Michael D. Coe stated:

[O]ur knowledge of ancient Maya thought must represent only a tiny fraction of the whole picture, for of the thousands of books in which the full extent of their learning and ritual was recorded, only four have survived to modern times (as though all that posterity knew of ourselves were to be based upon three prayer books and 'Pilgrim's Progress').

- *— Michael D. Coe, The Maya, London: Thames and Hudson, 6th ed., 1999, pp. 199–200.*

Most surviving pre-Columbian Maya writing dates to the Classic period and is contained in stone inscriptions from Maya sites, such as stelae, or on ceramics vessels. Other media include the aforementioned codices, stucco façades, frescoes, wooden lintels, cave walls, and portable artefacts crafted from a variety of materials, including bone, shell, obsidian, and jade.

Writing system

The Maya writing system (often called *hieroglyphs* from a superficial resemblance to Ancient Egyptian writing) is a logosyllabic writing system, combining a syllabary of phonetic signs representing syllables with logogram representing entire words. Among the writing systems of the Pre-Columbian New World, Maya script most closely represents the spoken language. At any one time, no more than around 500 glyphs were in use, some 200 of which (including variations) were phonetic.

The Maya script was in use up to the arrival of the Europeans, its use peaking during the Classic Period. In excess of 10,000 individual texts have been recovered, mostly inscribed on stone monuments, lintels, stelae and ceramics. The Maya also produced texts painted on a form of paper manufactured from processed tree-bark generally now known by its Nahuatl-language name *amatl* used to produce codices. The skill and knowledge of Maya writing persisted among segments of the population right up to the Spanish conquest. The knowledge was subsequently lost, as a result of the impact of the conquest on Maya society.

The decipherment and recovery of the knowledge of Maya writing has been a long and laborious process. Some elements were first deciphered in the late 19th and early 20th century, mostly the parts having to do with numbers, the Maya calendar, and astronomy. Major breakthroughs were made from the 1950s to 1970s, and accelerated rapidly thereafter. By the end of the 20th century, scholars were able to read the majority of Maya texts, and ongoing work continues to further illuminate the content.

Logosyllabic script

The basic unit of Maya logosyllabic text is the glyph block, which transcribes a word or phrase. The block is composed of one or more individual glyphs attached to each other to form the glyph block, with individual glyph blocks generally being separated by a space. Glyph blocks are usually arranged in a grid pattern. For ease of reference, epigraphers refer to glyph blocks from left to right alphabetically, and top to bottom numerically. Thus, any glyph block in a piece of text can be identified. C4 would be third block counting from the left, and the fourth block counting downwards. If a monument or artefact has more than one inscription, column labels are not repeated, rather they continue in the alphabetic series; if there are more than 26 columns, the labelling continues as A', B', etc. Numeric row labels restart from 1 for each discrete unit of text.

Although Mayan text may be laid out in varying manners, generally it is arranged into double columns of glyph blocks. The reading order of text starts at the top left (block A1), continues to the second block in the double-column (B1), then drops down a row and starts again from the left half of the double column (A2), and thus continues in zig-zag fashion. Once the bottom is reached, the inscription continues from the top left of the next double column. Where an inscription ends in a single (unpaired) column, this final column is usually read straight downwards.

Individual glyph blocks may be composed of a number of elements. These consist of the main sign, and any affixes. Main signs represent the major element of the block, and may be a noun, verb, adverb, adjective, or phonetic sign.

Some main signs are abstract, some are pictures of the object they represent, and others are "head variants", personifications of the word they represent. Affixes are smaller rectangular elements, usually attached to a main sign, although a block may be composed entirely of affixes.

Affixes may represent a wide variety of speech elements, including nouns, verbs, verbal suffixes, prepositions, pronouns, and more. Small sections of a main sign could be used to represent the whole main sign, and Maya scribes were highly inventive in their usage and adaptation of glyph elements.

Writing tools

Although the archaeological record does not provide examples of brushes or pens, analysis of ink strokes on the Postclassic codices suggests that it was applied with a brush with a tip fashioned from pliable hair. A Classic period sculpture from Copán, Honduras, depicts a scribe with an inkpot fashioned from a conch shell. Excavations at Aguateca uncovered a number of scribal artefacts from the residences of elite status scribes, including palettes and mortars and pestles.

Scribes and literacy

Commoners were illiterate; scribes were drawn from the elite. It is not known if all members of the aristocracy could read and write, although at least some women could, since there are representations of female scribes in Maya art. Maya scribes were called *aj tz'ib*, meaning "one who writes or paints".

There were probably scribal schools where members of the aristocracy were taught to write. Scribal activity is identifiable in the archaeological record; Jasaw Chan K'awiil I, king of Tikal, was interred with his paint pot. Some junior members of the Copán royal dynasty have also been found buried with their writing implements. A palace at Copán has been identified as that of a noble lineage of scribes; it is decorated with sculpture that includes figures holding ink pots.

Although not much is known about Maya scribes, some did sign their work, both on ceramics and on stone sculpture. Usually, only a single scribe signed a ceramic vessel, but multiple sculptors are known to have recorded their names on stone sculpture; eight sculptors signed one stela at Piedras Negras. However, most works remained unsigned by their artists.

Mathematics

In common with the other Mesoamerican civilizations, the Maya used a base 20 (vigesimal) system. The bar-and-dot counting system that is the base of Maya numerals was in use in Mesoamerica by 1000 BC; the Maya adopted it by the Late Preclassic, and added the symbol for zero. This may have been the earliest known occurrence of the idea of an explicit zero worldwide, although it may have been predated by the Babylonian system. The earliest explicit use of zero occurred on monuments dated to 357 AD. In its earliest uses, the zero served as a place holder, indicating an absence of a particular calendrical count. This later developed into a numeral that was used to perform calculation, and was used in hieroglyphic texts for more than a thousand years, until the writing system was extinguished by the Spanish.

The basic number system consists of a dot to represent one, and a bar to represent five. By the Postclassic period a shell symbol represented zero; during the Classic period other glyphs were used. The Maya numerals from 0 to 19 used repetitions of these symbols. The value of a numeral was determined by its position; as a numeral shifted upwards, its basic value multiplied by twenty. In this way, the lowest symbol would represent units, the next symbol up would represent multiples of twenty, and the symbol above that would represent multiples of 400, and so on. For example, the number 884 would be written with four dots on the lowest level, four dots on the next level up, and two dots on the next level after that, to give 4×1 + 4×20 + 2×400 = 884. Using this system, the Maya were able to record huge numbers. Simple addition could be performed by summing the dots and bars in two columns to give the result in a third column.

Calendar

The Maya calendrical system, in common with other Mesoamerican calendars, had its origins in the Preclassic period. However, it was the Maya that developed the calendar to its maximum sophistication, recording lunar and solar cycles, eclipses and movements of planets with great accuracy. In some cases, the Maya calculations were more accurate than equivalent calculations in the Old World; for example, the Maya solar year was calculated to greater accuracy than the Julian year.

The Maya calendar was intrinsically tied to Maya ritual, and it was central to Maya religious practices. The calendar combined a non-repeating Long Count with three interlocking cycles, each measuring a progressively larger period. These were the 260-day *tzolk'in*, the 365-day *haab'*, and the 52-year Calendar Round, resulting from the combination of the *tzolk'in* with the *haab'*. There were also additional calendric cycles, such as an 819-day cycle associated with the four quadrants of Maya cosmology, governed by four different aspects of the god

K'awiil. The basic unit in the Maya calendar was one day, or *k'in*, and 20 *k'in* grouped to form a *winal*. The next unit, instead of being multiplied by 20, as called for by the vigesimal system, was multiplied by 18 in order to provide a rough approximation of the solar year (hence producing 360 days). This 360-day year was called a *tun*. Each succeeding level of multiplication followed the vigesimal system.

The 260-day *tzolk'in* provided the basic cycle of Maya ceremony, and the foundations of Maya prophecy. No astronomical basis for this count has been proved, and it may be that the 260-day count is based on the human gestation period. This is reinforced by the use of the *tzolk'in* to record dates of birth, and provide corresponding prophecy. The 260-day cycle repeated a series of 20-day-names, with a number from 1 to 13 prefixed to indicated where in the cycle a particular day occurred.

The 365-day *haab* was produced by a cycle of eighteen named 20-day *winal*s, completed by the addition of a 5-day period called the *wayeb*. The *wayeb* was considered to be a dangerous time, when the barriers between the mortal and supernatural realms were broken, allowing malignant deities to cross over and interfere in human concerns. In a similar way to the *tz'olkin*, the named *winal* would be prefixed by a number (from 0 to 19), in the case of the shorter *wayeb* period, the prefix numbers ran 0 to 4. Since each day in the *tz'olkin* had a name and number (e.g. 8 Ajaw), this would interlock with the *haab*, producing an additional number and name, to give any day a more complete designation, for example 8 Ajaw 13 Keh. Such a day name could only recur once every 52 years, and this period is referred to by Mayanists as the Calendar Round. In most

Mesoamerican cultures, the Calendar Round was the largest unit for measuring time. As with any non-repeating calendar, the Maya measured time from a fixed start point. The Maya set the beginning of their calendar as the end of a previous cycle of *bak'tun*s, equivalent to a day in 3114 BC. This was believed by the Maya to be the day of the creation of the world in its current form. The Maya used the Long Count Calendar to fix any given day of the Calendar Round within their current great *Piktun* cycle consisting of either 20 *bak'tun*s. There was some variation in the calendar, specifically texts in Palenque demonstrate that the *piktun* cycle that ended in 3114 BC had only 13 *bak'tun*s, but others used a cycle of 13 + 20 *bak'tun* in the current *piktun*. Additionally, there may have been some regional variation in how these exceptional cycles were managed.

A full long count date consisted of an introductory glyph followed by five glyphs counting off the number of *bak'tun*s, *kat'un*s, *tun*s, *winal*s, and *k'in*s since the start of the current creation. This would be followed by the *tz'olkin* portion of the Calendar Round date, and after a number of intervening glyphs, the Long Count date would end with the *Haab* portion of the Calendar Round date.

Correlation of the Long Count calendar

Although the Calendar Round is still in use today, the Maya started using an abbreviated Short Count during the Late Classic period. The Short Count is a count of 13 k'atuns. The Book of Chilam Balam of Chumayel contains the only colonial reference to classic long-count dates. The most generally accepted correlation is the Goodman-Martínez-Thompson, or

GMT, correlation. This equates the Long Count date 11.16.0.0.0 13 Ajaw 8 Xul with the Gregorian date of 12 November 1539. Epigraphers Simon Martin and Nikolai Grube argue for a two-day shift from the standard GMT correlation. The Spinden Correlation would shift the Long Count dates back by 260 years; it also accords with the documentary evidence, and is better suited to the archaeology of the Yucatán Peninsula, but presents problems with the rest of the Maya region. The George Vaillant Correlation would shift all Maya dates 260 years later, and would greatly shorten the Postclassic period. Radiocarbon dating of dated wooden lintels at Tikal supports the GMT correlation.

Astronomy

The Maya made meticulous observations of celestial bodies, patiently recording astronomical data on the movements of the sun, moon, Venus, and the stars. This information was used for divination, so Maya astronomy was essentially for astrological purposes. Although Maya astronomy was mainly used by the priesthood to comprehend past cycles of time, and project them into the future to produce prophecy, it also had some practical applications, such as providing aid in crop planting and harvesting. The priesthood refined observations and recorded eclipses of the sun and moon, and movements of Venus and the stars; these were measured against dated events in the past, on the assumption that similar events would occur in the future when the same astronomical conditions prevailed. Illustrations in the codices show that priests made astronomical observations using the naked eye, assisted by crossed sticks as a sighting device. Analysis of the few remaining Postclassic codices has revealed that, at the time of European contact, the Maya had recorded eclipse tables, calendars, and astronomical knowledge that was more accurate at that time than comparable knowledge in Europe.

The Maya measured the 584-day Venus cycle with an error of just two hours. Five cycles of Venus equated to eight 365-day *haab* calendrical cycles, and this period was recorded in the codices.

The Maya also followed the movements of Jupiter, Mars and Mercury. When Venus rose as the Morning Star, this was associated with the rebirth of the Maya Hero Twins. For the Maya, the heliacal rising of Venus was associated with destruction and upheaval. Venus was closely associated with warfare, and the hieroglyph meaning "war" incorporated the glyph-element symbolizing the planet.

Sight-lines through the windows of the Caracol building at Chichen Itza align with the northernmost and southernmost extremes of Venus' path. Maya rulers launched military campaigns to coincide with the heliacal or cosmical rising of Venus, and would also sacrifice important captives to coincide with such conjunctions.

Solar and lunar eclipses were considered to be especially dangerous events that could bring catastrophe upon the world. In the *Dresden Codex*, a solar eclipse is represented by a serpent devouring the *k'in* ("day") hieroglyph. Eclipses were interpreted as the sun or moon being bitten, and lunar tables were recorded in order that the Maya might be able to predict them, and perform the appropriate ceremonies to ward off disaster.

Religion and mythology

In common with the rest of Mesoamerica, the Maya believed in a supernatural realm inhabited by an array of powerful deities who needed to be placated with ceremonial offerings and ritual practices. At the core of Maya religious practice was the worship of deceased ancestors, who would intercede for their living descendants in dealings with the supernatural realm. The earliest intermediaries between humans and the supernatural were shamans. Maya ritual included the use of hallucinogens for *chilan*, oracular priests. Visions for the *chilan* were likely facilitated by consumption of water lilies, which are hallucinogenic in high doses. As the Maya civilization developed, the ruling elite codified the Maya world view into religious cults that justified their right to rule. In the Late Preclassic, this process culminated in the institution of the divine king, the *k'uhul ajaw,* endowed with ultimate political and religious power.

The Maya viewed the cosmos as highly structured. There were thirteen levels in the heavens and nine in the underworld, with the mortal world in between. Each level had four cardinal directions associated with a different colour; north was white, east was red, south was yellow, and west was black. Major deities had aspects associated with these directions and colours.

Maya households interred their dead underneath the floors, with offerings appropriate to the social status of the family. There the dead could act as protective ancestors. Maya lineages were patrilineal, so the worship of a prominent male ancestor would be emphasised, often with a household shrine.

As Maya society developed, and the elite became more powerful, Maya royalty developed their household shrines into the great pyramids that held the tombs of their ancestors.

Belief in supernatural forces pervaded Maya life and influenced every aspect of it, from the simplest day-to-day activities such as food preparation, to trade, politics, and elite activities. Maya deities governed all aspects of the world, both visible and invisible. The Maya priesthood was a closed group, drawing its members from the established elite; by the Early Classic they were recording increasingly complex ritual information in their hieroglyphic books, including astronomical observations, calendrical cycles, history and mythology. The priests performed public ceremonies that incorporated feasting, bloodletting, incense burning, music, ritual dance, and, on certain occasions, human sacrifice.

During the Classic period, the Maya ruler was the high priest, and the direct conduit between mortals and the gods. It is highly likely that, among commoners, shamanism continued in parallel to state religion. By the Postclassic, religious emphasis had changed; there was an increase in worship of the images of deities, and more frequent recourse to human sacrifice.

Archaeologists painstakingly reconstruct these ritual practices and beliefs using several techniques. One important, though incomplete, resource is physical evidence, such as dedicatory caches and other ritual deposits, shrines, and burials with their associated funerary offerings. Maya art, architecture, and writing are another resource, and these can be combined with ethnographic sources, including records of Maya religious practices made by the Spanish during the conquest.

Human sacrifice

Blood was viewed as a potent source of nourishment for the Maya deities, and the sacrifice of a living creature was a powerful blood offering. By extension, the sacrifice of a human life was the ultimate offering of blood to the gods, and the most important Maya rituals culminated in human sacrifice. Generally only high status prisoners of war were sacrificed, with lower status captives being used for labour.

Important rituals such as the dedication of major building projects or the enthronement of a new ruler required a human offering. The sacrifice of an enemy king was the most prized, and such a sacrifice involved decapitation of the captive ruler in a ritual reenactment of the decapitation of the Maya maize god by the death gods. In AD 738, the vassal king K'ak' Tiliw Chan Yopaat of Quiriguá captured his overlord, Uaxaclajuun Ub'aah K'awiil of Copán and a few days later ritually decapitated him. Sacrifice by decapitation is depicted in Classic period Maya art, and sometimes took place after the victim was tortured, being variously beaten, scalped, burnt or disembowelled. Another myth associated with decapitation was that of the Hero Twins recounted in the *Popol Vuh*: playing a ballgame against the gods of the underworld, the heroes achieved victory, but one of each pair of twins was decapitated by their opponents.

During the Postclassic period, the most common form of human sacrifice was heart extraction, influenced by the rites of the Aztecs in the Valley of Mexico; this usually took place in the courtyard of a temple, or upon the summit of the pyramid. In one ritual, the corpse would be skinned by assistant priests, except for the hands and feet, and the officiating priest would then dress himself in the skin of the sacrificial victim and perform a ritual dance symbolizing the rebirth of life. Archaeological investigations indicate that heart sacrifice was practised as early as the Classic period.

Deities

The Maya world was populated by a great variety of deities, supernatural entities and sacred forces. The Maya had such a broad interpretation of the sacred that identifying distinct deities with specific functions is inaccurate. The Maya interpretation of deities was closely tied to the calendar, astronomy, and their cosmology. The importance of a deity, its characteristics, and its associations varied according to the movement of celestial bodies.

The priestly interpretation of astronomical records and books was therefore crucial, since the priest would understand which deity required ritual propitiation, when the correct ceremonies should be performed, and what would be an appropriate offering. Each deity had four manifestations, associated with the cardinal directions, each identified with a different colour. They also had a dual day-night/life-death aspect.

Itzamna was the creator god, but he also embodied the cosmos, and was simultaneously a sun god; K'inich Ahau, the day sun, was one of his aspects. Maya kings frequently identified themselves with K'inich Ahau. Itzamna also had a night sun aspect, the Night Jaguar, representing the sun in its journey through the underworld. The four Pawatuns supported the corners of the mortal realm; in the heavens, the Bacabs performed the same function. As well as their four main aspects, the Bakabs had dozens of other aspects that are not well understood. The four Chaacs were storm gods, controlling thunder, lightning, and the rains. The nine lords of the night each governed one of the underworld realms. Other important deities included the moon goddess, the maize god, and the Hero Twins.

The *Popol Vuh* was written in the Latin script in early colonial times, and was probably transcribed from a hieroglyphic book by an unknown K'iche' Maya nobleman. It is one of the most outstanding works of indigenous literature in the Americas.

The *Popul Vuh* recounts the mythical creation of the world, the legend of the Hero Twins, and the history of the Postclassic K'iche' kingdom. Deities recorded in the *Popul Vuh* include Hun Hunahpu, the K'iche' maize god, and a triad of deities led by the K'iche' patron Tohil, and also including the moon goddess Awilix, and the mountain god Jacawitz.

In common with other Mesoamerican cultures, the Maya worshipped feathered serpent deities. Such worship was rare during the Classic period, but by the Postclassic the feathered serpent had spread to both the Yucatán Peninsula and the Guatemalan Highlands. In Yucatán, the feathered serpent deity was Kukulkan, among the K'iche' it was Q'uq'umatz. Kukulkan had his origins in the Classic period War Serpent, *Waxaklahun Ubah Kan*, and has also been identified as the Postclassic version of the Vision Serpent of Classic Maya art. Although the cult of Kukulkan had its origins in these earlier Maya traditions, the worship of Kukulkan was heavily influenced by the Quetzalcoatl cult of central Mexico. Likewise, Q'uq'umatz had a composite origin, combining the attributes of Mexican Quetzalcoatl with aspects of the Classic period Itzamna.

Agriculture

The ancient Maya had diverse and sophisticated methods of food production. It was believed that shifting cultivation (swidden) agriculture provided most of their food, but it is now thought that permanent raised fields, terracing, intensive gardening, forest gardens, and managed fallows were also crucial to supporting the large populations of the Classic period in some areas. Indeed, evidence of these different agricultural systems persist today: raised fields connected by canals can be seen on aerial photographs. Contemporary rainforest species composition has significantly higher abundance of species of economic value to ancient Maya in areas that were densely populated in pre-Columbian times, and pollen records in lake sediments suggest that maize, manioc, sunflower seeds, cotton, and other crops have been cultivated in association with deforestation in Mesoamerica since at least 2500 BC.

The basic staples of the Maya diet were maize, beans, and squashes. These were supplemented with a wide variety of other plants either cultivated in gardens or gathered in the forest. At Joya de Cerén, a volcanic eruption preserved a record of foodstuffs stored in Maya homes, among them were chilies and tomatoes. Cotton seeds were in the process of being ground, perhaps to produce cooking oil. In addition to basic foodstuffs, the Maya also cultivated prestige crops such as cotton, cacao and vanilla. Cacao was especially prized by the elite, who consumed chocolate beverages. Cotton was spun, dyed, and woven into valuable textiles in order to be traded.

The Maya had few domestic animals; dogs were domesticated by 3000 BC, and the Muscovy duck by the Late Postclassic. Ocellated turkeys were unsuitable for domestication, but were rounded up in the wild and penned for fattening. All of these were used as food animals; dogs were additionally used for hunting. It is possible that deer were also penned and fattened.

Maya sites

There are hundreds of Maya sites spread across five countries: Belize, El Salvador, Guatemala, Honduras and Mexico. The six sites with particularly outstanding architecture or sculpture are Chichen Itza, Palenque, Uxmal, and Yaxchilan in Mexico, Tikal in Guatemala and Copán in Honduras. Other important, but difficult to reach, sites include Calakmul and El Mirador.

The principal sites in the Puuc region, after Uxmal, are Kabah, Labna, and Sayil. In the east of the Yucatán Peninsula are Coba and the small site of Tulum. The Río Bec sites of the base of the peninsula include Becan, Chicanná, Kohunlich, and Xpuhil. The most noteworthy sites in Chiapas, other than Palenque and Yaxchilan, are Bonampak and Toniná. In the Guatemalan Highlands are Iximche, Kaminaljuyu, Mixco Viejo, and Q'umarkaj (also known as Utatlán). In the northern Petén lowlands of Guatemala there are many sites, though apart from Tikal access is generally difficult. Some of the Petén sites are Dos Pilas, Seibal, and Uaxactún. Important sites in Belize include Altun Ha, Caracol, and Xunantunich.

Chapter 5

Ancient Greek Technology

Ancient Greek technology developed during the 5th century BC, continuing up to and including the Roman period, and beyond. Inventions that are credited to the ancient Greeks include the gear, screw, rotary mills, bronze casting techniques, water clock, water organ, torsion catapult, the use of steam to operate some experimental machines and toys, and a chart to find prime numbers. Many of these inventions occurred late in the Greek period, often inspired by the need to improve weapons and tactics in war. However, peaceful uses are shown by their early development of the watermill, a device which pointed to further exploitation on a large scale under the Romans. They developed surveying and mathematics to an advanced state, and many of their technical advances were published by philosophers, like Archimedes and Heron.

Water technology

Some fields that were encompassed in the area of water resources (mainly for urban use) included groundwater exploitation, construction of aqueducts for water supply, storm water and wastewater sewerage systems, flood protection. and drainage, construction and use of fountains, baths and other sanitary and purgatory facilities, and even recreational uses of water. Excellent examples of these technologies include the drainage system found in the Anatolian west coast, which featured an unusual masonry outlet structure that allowed self-cleaning of the drainage outlet. The technology, which demonstrated the Greek understanding of the importance of hygienic conditions to public health, was part of an elaborate drainage system and underground water supply network.

Mining

The Greeks developed extensive silver mines at Laurium, the profits from which helped support the growth of Athens as a city-state. It involved mining the ores in underground galleries, washing it and smelting it to produce the metal. Elaborate washing tables still exist at the site, which used rainwater held in cisterns and collected during the winter months. Mining also helped to create currency by the conversion of the metal into coinage. Greek mines had tunnels that were as deep as 330 feet and were worked by slaves using picks and iron hammers. The extracted ore were lifted by small skips hauled by a rope that was sometimes guided by a wheel placed against the rim of the mine shaft.

Chapter 6

Ancient Roman Technology

Roman technology is the collection of antiques, skills, methods, processes, and engineering practices which supported Roman civilization and made possible the expansion of the economy and military of ancient Rome (753 BC – 476 AD).

The Roman Empire was one of the most technologically advanced civilizations of antiquity, with some of the more advanced concepts and inventions forgotten during the turbulent eras of Late Antiquity and the early Middle Ages. Gradually, some of the technological feats of the Romans were rediscovered and/or improved upon during the Middle Ages and the beginning of the Modern Era; with some in areas such as civil engineering, construction materials, transport technology, and certain inventions such as the mechanical reaper, not improved upon until the 19th century. The Romans achieved high levels of technology in large part because they borrowed technologies from the Greeks, Etruscans, Celts, and others.

With limited sources of power, the Romans managed to build impressive structures, some of which survive to this day. The durability of Roman structures, such as roads, dams, and buildings, is accounted for the building techniques and practices they utilized in their construction projects. Rome and its surrounding area contained various types of volcanic materials, which Romans experimented with the creation of building materials, particularly cements and mortars. Along with concrete, the Romans used stone, wood, and marble as building materials. They used these materials to construct civil engineering projects for their cities and transportation devices for land and sea travel.

The Romans also contributed to the development of technologies of the battlefield. Warfare was an essential aspect of Roman society and culture. The military was not only used for territorial acquisition and defense, but also as a tool for civilian administrators to use to help staff provincial governments and assist in construction projects. The Romans adopted, improved, and developed military technologies for foot soldiers, cavalry, and siege weapons for land and sea environments.

Having familiar relations with warfare, the Romans became accustomed to physical injuries. To combat physical injuries sustained in civilian and military spheres, the Romans innovated medical technologies, particularly surgical practices and techniques.

Types of power

Human power

The most readily available sources of power to the ancients were human power and animal power. An obvious utilization of human power is the movement of objects. For objects ranging from 20 to 80 pounds a single person can generally suffice. For objects of greater weight, more than one person may be required to move the object. A limiting factor in using multiple people to move objects is the available amount of grip space.

To overcome this limiting factor, mechanical devices were developed to assist in the manipulation of objects. One device being the windlass which used ropes and pulleys to manipulate objects. The device was powered by multiple people pushing or pulling on handspikes attached to a cylinder.

Human power was also a factor in the movement of ships, in particularly warships. Though wind-powered sails were the dominate form of power in water transportation, rowing was often used by military craft during battle engagements.

Animal power

- The primary usage of animal power was for transportation. Several species of animals were used for differing tasks. Oxen are strong creatures that do not require the finest pasture. Being strong and cheap to maintain, oxen were used to farm and transport large masses of goods. A disadvantage to using oxen is that they are slow. If speed was desired, horses were called upon. The main environment which called for speed was the battlefield, with horses being used in the cavalry and scouting parties. For carriages carrying passengers or light materials donkeys or mules were generally used, as they were faster than oxen and cheaper on fodder than horses. Other than being used as a means of transportation, animals were also employed in the operation of rotary mills.

Beyond the confines of the land, a schematic for a ship propelled by animals has been discovered. The work known as

Anonymus De Rebus Bellicus describes a ship powered by oxen. Wherein oxen are attached to a rotary, moving in a circle on a deck floor, spinning two paddle wheels, one on either side of the ship. The likelihood that such a ship was ever built is low, due to the impracticality of controlling animals on a watercraft.

Water power

Power from water was generated through the use of a water wheel. A water wheel had two general designs: the undershot and the overshot. The undershot water wheel generated power from the natural flow of a running water source pushing upon the wheel's submerged paddles. The overshot water wheel generated power by having water flow over its buckets from above. This was usually achieved by building an aqueduct above the wheel. Although it is possible to make the overshot water wheel 70 percent more efficient than the undershot, the undershot was generally the preferred water wheel. The reason being, the economic cost to building an aqueduct was too high for the mild benefit of having the water wheel turn faster. The primary purpose of water wheels were to generate power for milling operations and to raise water above a system's natural height. Evidence also exists that water wheels were used to power the operation of saws, though only scant descriptions of such devices remain.

Wind power

Wind power was used in the operation of watercraft, through the use of sails. Windmills do not appear to have been created in Ancient times.

Solar power

The Romans used the Sun as a passive solar heat source for buildings, such as bath houses. Thermae were built with large windows facing southwest, the location of the Sun at the hottest time of day.

Theoretical types of power

Steam power

The generation of power through steam remained theoretical in the Roman world. Hero of Alexandria published schematics of a steam device that rotated a ball on a pivot. The device used heat from a cauldron to push steam through a system of tubes towards the ball. The device produced roughly 1500 rpm but would never be practical on an industrial scale as the labour requirements to operate, fuel and maintain the heat of the device would have been too great of a cost.

Technology as a craft

Roman technology was largely based on a system of crafts. Technical skills and knowledge were contained within the particular trade, such as stonemasons. In this sense, knowledge was generally passed down from a tradesman master to a tradesman apprentice. Since there are only a few sources from which to draw upon for technical information, it is theorized that tradesmen kept their knowledge a secret. Vitruvius, Pliny the Elder and Frontinus are among the few writers who have published technical information about Roman technology. There was a corpus of manuals on basic mathematics and science such as the many books by Archimedes, Ctesibius, Heron (a.k.a. Hero of Alexandria), Euclid and so on. Not all of the manuals which were available to the Romans have survived, as lost works illustrate.

Engineering and construction

Wood

The Romans created fireproof wood by coating the wood with alum.

Stone

It was ideal to mine stones from quarries that were situated as close to the site of construction as possible, to reduce the cost of transportation. Stone blocks were formed in quarries by punching holes in lines at the desired lengths and widths. Then, wooden wedges were hammered into the holes. The holes were then filled with water so that the wedges would swell with enough force to cut the stone block out of the Earth. Blocks with the dimensions of 23yds by 14ft by 15ft have been found, with weights of about 1000 tons. There is evidence that saws were developed to cut stone in the Imperial age. Initially, Romans used saws powered by hand to cut stone, but later went on to develop stone cutting saws powered by water.

Cements

The ratio of the mixture of Roman lime mortars depended upon where the sand for the mixture was acquired. For sand gathered at a river or sea, the mixture ratio was two parts sand, one part lime, and one part powdered shells. For sand gathered further inland, the mixture was three parts sand and one part lime. The lime for mortars was prepared in limekilns, which were underground pits designed to block out the wind.

Another type of Roman mortar is known as pozzolana mortar. Pozzolana is a volcanic clay substance located in and around Naples. The mixture ratio for the cement was two parts pozzolana and one part lime mortar. Due to its composition, pozzolana cement was able to form in water and has been found to be as hard as natural forming rock.

Cranes

Cranes were used for construction work and possibly to load and unload ships at their ports, although for the latter use there is according to the "present state of knowledge" still no evidence. Most cranes were capable of lifting about 6–7 tons of cargo, and according to a relief shown on Trajan's column were worked by treadwheel.

Buildings

The Pantheon

The Romans designed the Pantheon thinking about the concepts of beauty, symmetry, and perfection. The Romans incorporated these mathematical concepts into their public works projects. For instance, the concept of perfect numbers were used in the design of the Pantheon by embedding 28 coffers into the dome. A perfect number is a number where its factors add up to itself. So, the number 28 is considered to be a perfect number, because its factors of 1, 2, 4, 7, and 14 add together to equal 28. Perfect numbers are extremely rare, with there being only one number for each quantity of digits (one for single digits, double digits, triple digits, quadruple digits, etc.). Embodying mathematical concepts of beauty, symmetry, and perfection, into the structure conveys the technical sophistication of Roman engineers.

Cements were essential to the design of the Pantheon. The mortar used in the construction of the dome is made up of a mixture of lime and the volcanic powder known as, pozzolana. The concrete is suited for the use in constructing thick walls as it does not require to be completely dry in order to cure.

The construction of the Pantheon was a massive undertaking, requiring large quantities of resources and man-hours.

Delaine estimates the amount of total manpower needed in the construction the Pantheon to be about 400 000 man-days.

Hagia Sophia

Although the Hagia Sophia was constructed after the fall of the Western empire, its construction incorporated the building materials and techniques signature to ancient Rome. The building was constructed using pozzolana mortar. Evidence for the use of the substance comes from the sagging of the structures arches during construction, as a distinguishing feature of pozzalana mortar is the large amount of time it needs to cure. The engineers had to remove decorative walls in order to let the mortar cure.

The pozzalana mortar used in the construction of the Hagia Sophia does not contain volcanic ash but instead crushed brick dust. The composition of the materials used in pozzalana mortar leads to an increased tensile strength. A mortar composed of mostly lime has a tensile strength of roughly 30 psi whereas pozzalana mortar using crushed brick dust has a tensile strength of 500 psi. The advantage of using pozzalana mortar in the construction of the Hagia Sophia is the increase in strength of the joints. The mortar joints used in the structure are wider than one would expect in a typical brick and mortar structure. The fact of the wide mortar joints suggests the designers of the Hagia Sophia knew about the high tensile strength of the mortar and incorporated it accordingly.

Waterworks

Aqueducts

- The Romans constructed numerous aqueducts to supply water. The city of Rome itself was supplied by eleven aqueducts made of limestone that provided the city with over 1 million cubic metres of water each day, sufficient for 3.5 million people even in modern-day times, and with a combined length of 350 kilometres (220 mi).

Water inside the aqueducts depended entirely on gravity. The raised stone channels in which the water traveled were slightly slanted. The water was carried directly from mountain springs. After it had gone through the aqueduct, the water was collected in tanks and fed through pipes to fountains, toilets, etc. The main aqueducts in Ancient Rome were the Aqua Claudia and the Aqua Marcia. Most aqueducts were constructed below the surface with only small portions above ground supported by arches. The longest Roman aqueduct, 178 kilometres (111 mi) in length, was traditionally assumed to be that which supplied the city of Carthage. The complex system built to supply Constantinople had its most distant supply drawn from over 120 km away along a sinuous route of more than 336 km.

Roman aqueducts were built to remarkably fine tolerances, and to a technological standard that was not to be equaled until modern times. Powered entirely by gravity, they transported very large amounts of water very efficiently. Sometimes, where depressions deeper than 50 metres had to be crossed, inverted siphons were used to force water uphill. An aqueduct also supplied water for the overshot wheels at Barbegal in Roman Gaul, a complex of water mills hailed as "the greatest known concentration of mechanical power in the ancient world".

Roman aqueducts conjure images of water travelling long distances across arched bridges, however; only 5 percent of the water being transported along the aqueduct systems traveled by way of bridges. Roman engineers worked to make the routes of aqueducts as practical as possible. In practice, this meant designing aqueducts that flowed ground level or below surface level, as these were more cost effective than building bridges considering the cost of construction and maintenance for bridges was higher than that of surface and sub-surface elevations. Aqueduct bridges were often in need of repairs and spent years at a time in disuse. Water theft from the aqueducts was a frequent problem which led to difficulties in estimating the amount of water flowing through the channels. To prevent the channels of the aqueducts from eroding, a plaster known as opus signinum was used. The plaster incorporated crushed terracotta in the typical Roman mortar mixture of pozzolana rock and lime.

Dams

The Romans built dams for water collection, such as the Subiaco Dams, two of which fed Anio Novus, one of the largest aqueducts of Rome. They built 72 dams in just one country, Spain and many more are known across the Empire, some of which are still in use. At one site, Montefurado in Galicia, they appear to have built a dam across the river Sil to expose alluvial gold deposits in the bed of the river. The site is near the spectacular Roman gold mine of Las Medulas. Several earthen dams are known from Britain, including a well-preserved example from Roman Lanchester, Longovicium, where it may have been used in industrial-scale smithing or smelting, judging by the piles of slag found at this site in northern England. Tanks for holding water are also common along aqueduct systems, and numerous examples are known from just one site, the gold mines at Dolaucothi in west Wales. Masonry dams were common in North Africa for providing a reliable water supply from the wadis behind many settlements.

The Romans built dams to store water for irrigation. They understood that spillways were necessary to prevent the erosion of earth-packed banks. In Egypt, the Romans adopted the water technology known as wadi irrigation from the Nabataeans. Wadis were a technique developed to capture large amounts of water produced during the seasonal floods and store it for the growing season. The Romans successfully developed the technique further for a larger scale.

Sanitation

The Romans did not invent plumbing or toilets, but instead borrowed their waste disposal system from their neighbors, particularly the Minoans. A waste disposal system was not a new invention, but rather had been around since 3100 BCE, when one was created in the Indus River Valley The Roman public baths, or *thermae* served hygienic, social and cultural functions.

The baths contained three main facilities for bathing. After undressing in the apodyterium or changing room, Romans would proceed to the tepidarium or warm room. In the moderate dry heat of the tepidarium, some performed warm-up exercises and stretched while others oiled themselves or had slaves oil them. The tepidarium's main purpose was to promote sweating to prepare for the next room, the caldarium or hot room. The caldarium, unlike the tepidarium, was extremely humid and hot. Temperatures in the caldarium could reach 40 degrees Celsius (104 degrees Fahrenheit). Many contained steam baths and a cold-water fountain known as the labrum. The last room was the frigidarium or cold room, which offered a cold bath for cooling off after the caldarium. The Romans also had flush toilets.

Roman baths

The containment of heat in the rooms was important in the operation of the baths, as to avoid patrons from catching colds.

To prevent doors from being left open, the door posts were installed at an inclined angle so that the doors would automatically swing shut. Another technique of heat efficiency was the use of wooden benches over stone, as wood conducts away less heat.

Transportation

Roads

The Romans primarily built roads for their military. Their economic importance was probably also significant, although wagon traffic was often banned from the roads to preserve their military value. In total, more than 400,000 kilometres (250,000 mi) of roads were constructed, 80,500 kilometres (50,000 mi) of which were stone-paved.

Way stations providing refreshments were maintained by the government at regular intervals along the roads. A separate system of changing stations for official and private couriers was also maintained. This allowed a dispatch to travel a maximum of 800 kilometres (500 mi) in 24 hours by using a relay of horses.

The roads were constructed by digging a pit along the length of the intended course, often to bedrock. The pit was first filled with rocks, gravel or sand and then a layer of concrete. Finally, they were paved with polygonal rock slabs. Roman roads are considered the most advanced roads built until the early 19th century. Bridges were constructed over waterways. The roads were resistant to floods and other environmental hazards. After the fall of the Roman Empire the roads were still usable and used for more than 1000 years.

Most Roman cities were shaped like a square. There were 4 main roads leading to the center of the city, or forum. They formed a cross shape, and each point on the edge of the cross was a gateway into the city. Connecting to these main roads were smaller roads, the streets where people lived.

Bridges

Roman bridges were built with stone and/or concrete and utilized the arch. Built in 142 BC, the Pons Aemilius, later named *Ponte Rotto* (broken bridge) is the oldest Roman stone bridge in Rome, Italy. The biggest Roman bridge was Trajan's bridge over the lower Danube, constructed by Apollodorus of Damascus, which remained for over a millennium the longest bridge to have been built both in terms of overall and span length. They were most of the time at least 60 feet (18 m) above the body of water.

Carts

Roman carts had many purposes and came in a variety of forms. Freight carts were used to transport goods. Barrel carts were used to transport liquids. The carts had large cylindrical barrels laid horizontally with their tops facing forward. For transporting building materials, such as sand or soil, the Romans used carts with high walls. Public transportation carts were also in use with some designed with sleeping accommodations for up to six people.

The Romans developed a railed cargo system for transporting heavy loads. The rails consisted of grooves embedded into existing stone roadways. The carts used in such a system had large block axles and wooden wheels with metal casings.

Carts also contained brakes, elastic suspensions and bearings. The elastic suspension systems used leather belts attached bronze supports to suspend the carriage above the axles. The system helped to create a smoother ride by reducing the vibration. The Romans adopted bearings developed by the Celts. The bearings decreased rotational friction by using mud to lubricate stone rings.

Industrial

Mining

The Romans also made great use of aqueducts in their extensive mining operations across the empire, some sites such as Las Medulas in north-west Spain having at least 7 major channels entering the minehead. Other sites such as Dolaucothi in south Wales was fed by at least 5 leats, all leading to reservoirs and tanks or cisterns high above the present opencast. The water was used for hydraulic mining, where streams or waves of water are released onto the hillside, first to reveal any gold-bearing ore, and then to work the ore itself. Rock debris could be sluiced away by hushing, and the water also used to douse fires created to break down the hard rock and veins, a method known as fire-setting.

Alluvial gold deposits could be worked and the gold extracted without needing to crush the ore. Washing tables were fitted below the tanks to collect the gold-dust and any nuggets present. Vein gold needed crushing, and they probably used crushing or stamp mills worked by water-wheels to comminute the hard ore before washing.

Large quantities of water were also needed in deep mining to remove waste debris and power primitive machines, as well as for washing the crushed ore. Pliny the Elder provides a detailed description of gold mining in book xxxiii of his Naturalis Historia, most of which has been confirmed by archaeology. That they used water mills on a large scale elsewhere is attested by the flour mills at Barbegal in southern France, and on the Janiculum in Rome.

Military technology

Foot Soldier

Weaponry

- Pilum (spear): The Roman heavy spear was a weapon favored by legionaries and weighed approximately five pounds. The innovated javelin was designed to be used only once and was destroyed upon initial use. This ability prevented the enemy from reusing spears. All soldiers carried two versions of this weapon: a primary spear and a backup. A solid block of wood in the middle of the weapon provided legionaries protection for their hands while carrying the device. According to Polybius, historians have records of "how the Romans threw their spears and then charged with swords". This tactic seemed to be common practice among Roman infantry.

Armour

While heavy, intricate armour was not uncommon (cataphracts), the Romans perfected a relatively light, full torso armour made of segmented plates (lorica segmentata). This segmented armour provided good protection for vital areas, but did not cover as much of the body as lorica hamata or chainmail. The lorica segmentata provided better protection, but the plate bands were expensive and difficult to produce and difficult to repair in the field. Generally, chainmail was cheaper, easier to produce, and simpler to maintain, was one-size-fits-all, and was more comfortable to wear – thus, it remained the primary form of armour even when lorica segmentata was in use.

Tactics

Testudo is a tactical military maneuver original to Rome. The tactic was implemented by having units raise their shields in order to protect themselves from enemy projectiles raining down on them. The strategy only worked if each member of the testudo protected his comrade. Commonly used during siege battles, the "sheer discipline and synchronization required to form a Testudo" was a testament to the abilities of legionnaires. Testudo, meaning tortoise in Latin, "was not the norm, but rather adopted in specific situations to deal with particular threats on the battlefield". The Greek phalanx and other Roman formations were a source of inspiration for this maneouver.

Cavalry

The Roman cavalry saddle had four horns [1] and is believed to have been copied from Celtic peoples.

Siege warfare

Roman siege engines such as ballistas, scorpions and onagers were not unique. But the Romans were probably the first people to put ballistas on carts for better mobility on campaigns. On the battlefield, it is thought that they were used to pick off enemy leaders. There is one account of the use of artillery in battle from Tacitus, Histories III,23:

On engaging they drove back the enemy, only to be driven back themselves, for the Vitellians had concentrated their artillery on the raised road that they might have free and open ground from which to fire; their earlier shots had been scattered and had struck the trees without injuring the enemy. A ballista of enormous size belonging to the Fifteenth legion began to do great harm to the Flavians' line with the huge stones that it hurled; and it would have caused wide destruction if it had not been for the splendid bravery of two soldiers, who, taking some shields from the dead and so disguising themselves, cut the ropes and springs of the machine.

In addition to innovations in land warfare, the Romans also developed the Corvus (boarding device) a movable bridge that could attach itself to an enemy ship and allow the Romans to board the enemy vessel. Developed during the First Punic War it allowed them to apply their experience in land warfare on the seas.

Ballistas and onagers

- While core artillery inventions were notably founded by the Greeks, Rome saw opportunity in the ability to enhance this long range artillery. Large artillery pieces such as Carroballista and Onagers bombarded enemy lines, before full ground assault by infantry. The manuballista would "often be described as the most advanced two-armed torsion engine used by the Roman Army". The weapon often looks like a mounted crossbow capable of shooting projectiles. Similarly, the onager "named after the wild ass because of its 'kick'," was a larger weapon that was capable of hurling large projectiles at walls or forts. Both were very capable machines of war and were put to use by the Roman military.

The Helepolis

The helepolis was a transportation vehicle used to besiege cities. The vehicle had wooden walls to shield soldiers as they were transported toward the enemy's walls. Upon reaching the walls, the soldiers would disembark at the top of the 15m tall structure and drop on to the enemy's ramparts. To be effective in combat, the helepolis was designed to be self-propelled. The self-propelled vehicles were operated using two types of motors: an internal motor powered by humans, or a counterweight motor powered by gravity.

The human-powered motor used a system of ropes that connected the axles to a capstan. It has been calculated that at least 30 men would be required to turn the capstan in order to exceed the force required to move the vehicle. Two capstans may have been used instead of just the one, reducing the amount of men needed per capstan to 16, for a total of 32 to power the helepolis. The gravity-powered counterweight motor used a system of ropes and pulleys to propel the vehicle. Ropes were wrapped around the axles, strung through a pulley system that connected them to a counterweight hanging at the top of the vehicle. The counterweights would have been made of lead or a bucket filled with water. The lead counterweight was encapsulated in a pipe filled with seeds to control its fall. The water bucket counterweight was emptied when it reached the bottom of the vehicle, raised back to the top, and filled with water using a reciprocating water pump, so that motion could again be achieved.

It has been calculated that to move a helepolis with a mass of 40000kg, a counterweight with a mass of 1000kg was needed.

Greek fire

- Originally an incendiary weapon adopted from the Greeks in 7th century AD, the Greek fire "is one of the very few contrivances whose gruesome effectiveness was noted by" many sources. Roman innovators made this already lethal weapon even more deadly. Its nature is often described as a "precursor to napalm". Military strategists often put the weapon to good use during naval battles, and the ingredients to its construction "remained a closely guarded military secret". Despite this, the devastation caused by Greek fire in combat is indisputable.

Transportation

Pontoon bridge

Mobility, for a military force, was an essential key to success. Although this was not a Roman invention, as there were instances of "ancient Chinese and Persians making use of the floating mechanism", Roman generals used the innovation to great effect in campaigns.

Furthermore, engineers perfected the speed at which these bridges were constructed. Leaders surprised enemy units to great effect by speedily crossing otherwise treacherous bodies of water. Lightweight crafts were "organized and tied together with the aid of planks, nails and cables".

Rafts were more commonly used instead of building new makeshift bridges, enabling quick construction and deconstruction. The expedient and valuable innovation of the pontoon bridge also accredited its success to the excellent abilities of Roman Engineers.

Medical technology

Surgery

Although various levels of medicine were practiced in the ancient world, the Romans created or pioneered many innovative surgeries and tools that are still in use today such as hemostatic tourniquets and arterial surgical clamps. Rome was also responsible for producing the first battlefield surgery unit, a move that paired with their contributions to medicine made the Roman army a force to be reckoned with. They also used a rudimentary version of antiseptic surgery years before its use became popular in the 19th century and possessed very capable doctors.

Chapter 7

History of Technology in China

Ancient Chinese scientists and engineers made significant scientific innovations, findings and technological advances across various scientific disciplines including the natural sciences, engineering, medicine, military technology, mathematics, geology and astronomy.

Among the earliest inventions were the abacus, the sundial, and the Kongming lantern. The *Four Great Inventions,*the compass, gunpowder, papermaking, and printing – were among the most important technological advances, only known to Europe by the end of the Middle Ages 1000 years later. The Tang dynasty (AD 618–906) in particular was a time of great innovation. A good deal of exchange occurred between Western and Chinese discoveries up to the Qing dynasty.

The Jesuit China missions of the 16th and 17th centuries introduced Western science and astronomy, then undergoing its own revolution, to China, and knowledge of Chinese technology was brought to Europe. In the 19th and 20th centuries the introduction of Western technology was a major factor in the modernization of China. Much of the early Western work in the history of science in China was done by Joseph Needham.

Mo Di and the School of Names

The Warring States period began 2500 years ago at the time of the invention of the crossbow. Needham notes that the invention of the crossbow "far outstripped the progress in defensive armor", which made the wearing of armor useless to the princes and dukes of the states. At this time, there were also many nascent schools of thought in China—the Hundred Schools of Thought (諸子百家), scattered among many polities. The schools served as communities which advised the rulers of these states. Mo Di (墨翟 Mozi, 470 BCE–c. 391 BCE) introduced concepts useful to one of those rulers, such as defensive fortification. One of these concepts, *fa* (法 principle or method) was extended by the School of Names (名家*Ming jia*, *ming*=name), which began a systematic exploration of logic. The development of a school of logic was cut short by the defeat of Mohism's political sponsors by the Qin dynasty, and the subsumption of *fa* as law rather than method by the Legalists (法家*Fa jia*).

Needham further notes that the Han dynasty, which conquered the short-lived Qin, were made aware of the need for law by Lu Jia and by Shusun Tong, as defined by the scholars, rather than the generals.

You conquered the empire on horseback, but from horseback you will never succeed in ruling it.

- *— Lu Jia*

Derived from Taoist philosophy, one of the newest longstanding contributions of the ancient Chinese are in Traditional Chinese medicine, including acupuncture and herbal medicine. The practice of acupuncture can be traced back as far as the 1st millennium BC and some scientists believe that there is evidence that practices similar to acupuncture were used in Eurasia during the early Bronze Age.

Using shadow clocks and the abacus (both invented in the ancient Near East before spreading to China), the Chinese were able to record observations, documenting the first recorded solar eclipse in 2137 BC, and making the first recording of any planetary grouping in 500 BC. These claims, however, are highly disputed and rely on much supposition. The *Book of Silk* was the first definitive atlas of comets, written *c.* 400 BC. It listed 29 comets (referred to as *sweeping stars*) that appeared over a period of about 300 years, with renderings of comets describing an event its appearance corresponded to.

In architecture, the pinnacle of Chinese technology manifested itself in the Great Wall of China, under the first Chinese EmperorQin Shi Huang between 220 and 200 BC. Typical Chinese architecture changed little from the succeeding Han dynasty until the 19th century. The Qin dynasty also developed the crossbow, which later became the mainstream weapon in Europe. Several remains of crossbows have been found among the soldiers of the Terracotta Army in the tomb of Qin Shi Huang.

Han dynasty

The Eastern Han dynasty scholar and astronomer Zhang Heng (78–139 AD) invented the first water-powered rotating armillary sphere (the first armillary sphere having been invented by the GreekEratosthenes), and catalogued 2,500 stars and over 100 constellations. In 132, he invented the first seismological detector, called the "*Houfeng Didong Yi*" ("Instrument for inquiring into the wind and the shaking of the earth"). According to the *History of Later Han Dynasty* (25–220 AD), this seismograph was an urn-like instrument, which would drop one of eight balls to indicate when and in which direction an earthquake had occurred. On June 13, 2005, Chinese seismologists announced that they had created a replica of the instrument.

The mechanical engineer Ma Jun (c. 200–265 AD) was another impressive figure from ancient China. Ma Jun improved the design of the silk loom, designed mechanical chain pumps to irrigate palatial gardens, and created a large and intricate mechanical puppettheatre for Emperor Ming of Wei, which was operated by a large hidden waterwheel. However, Ma Jun's most impressive invention was the south-pointing chariot, a complex mechanical device that acted as a mechanical compass vehicle. It incorporated the use of a differential gear in order to apply equal amount of torque to wheels rotating at different speeds, a device that is found in all modern automobiles.

Sliding calipers were invented in China almost 2,000 years ago. The Chinese civilization was the earliest civilization to experiment successfully with aviation, with the kite and Kongming lantern (proto Hot air balloon) being the first flying machines.

"Four Great Inventions"

The "Four Great Inventions" (simplified Chinese: 四大发明; traditional Chinese: 四大發明; pinyin: *sì dà fāmíng*) are the compass, gunpowder, papermaking and printing. Paper and printing were developed first. Printing was recorded in China in the Tang Dynasty, although the earliest surviving examples of printed cloth patterns date to before 220. Pin-pointing the development of the compass can be difficult: the magnetic attraction of a needle is attested by the *Louen-heng*, composed between AD 20 and 100, although the first undisputed magnetized needles in Chinese literature appear in 1086.

By AD 300, Ge Hong, an alchemist of the Jin dynasty, conclusively recorded the chemical reactions caused when saltpetre, pine resin and charcoal were heated together, in *Book of the Master of the Preservations of Solidarity*. Another early record of gunpowder, a Chinese book from *c*. 850 AD, indicates:

"Some have heated together sulfur, realgar and saltpeter with honey; smoke and flames result, so that their hands and faces have been burnt, and even the whole house where they were working burned down."

These four discoveries had an enormous impact on the development of Chinese civilization and a far-ranging global impact. Gunpowder, for example, spread to the Arabs in the 13th century and thence to Europe. According to EnglishphilosopherFrancis Bacon, writing in *Novum Organum*:

Printing, gunpowder and the compass: These three have changed the whole face and state of things throughout the world; the first in literature, the second in warfare, the third in navigation; whence have followed innumerable changes, in so much that no empire, no sect, no star seems to have exerted greater power and influence in human affairs than these mechanical discoveries.

One of the most important military treatises of all Chinese history was the *Huo Long Jing* written by Jiao Yu in the 14th century.

For gunpowder weapons, it outlined the use of fire arrows and rockets, fire lances and firearms, land mines and naval mines, bombards and cannons, two stage rockets, along with different compositions of gunpowder, including 'magic gunpowder', 'poisonous gunpowder', and 'blinding and burning gunpowder' (refer to his article).

For the 11th century invention of ceramic movable type printing by Bi Sheng (990–1051), it was enhanced by the wooden movable type of Wang Zhen in 1298 and the bronze metal movable type of Hua Sui in 1490.

China's scientific revolution

Among the engineering accomplishments of early China were matches, dry docks, the double-action piston pump, cast iron, the ironplough, the horse collar, the multi-tube seed drill, the wheelbarrow, the suspension bridge, the parachute, natural gas as fuel, the raised-relief map, the propeller, the sluice gate, and the pound lock. The Tang dynasty (AD 618–907) and Song dynasty (AD 960–1279) in particular were periods of great innovation.

In the 7th century, book-printing was developed in China, Korea and Japan, using delicate hand-carved wooden blocks to print individual pages. The 9th century *Diamond Sutra* is the earliest known printed document. Movable type was also used in China for a time, but was abandoned because of the number of characters needed; it would not be until Johannes Gutenberg that the technique was reinvented in a suitable environment.

In addition to gunpowder, the Chinese also developed improved delivery systems for the Byzantine weapon of Greek fire, Meng Huo You and Pen Huo Qi first used in China *c.* 900. Chinese illustrations were more realistic than in Byzantine manuscripts, and detailed accounts from 1044 recommending its use on city walls and ramparts show the brass container as fitted with a horizontal pump, and a nozzle of small diameter. The records of a battle on the Yangtze near Nanjing in 975 offer an insight into the dangers of the weapon, as a change of wind direction blew the fire back onto the Song forces.

Song Dynasty

The Song dynasty (960–1279) brought a new stability for China after a century of civil war, and started a new area of modernisation by encouraging examinations and meritocracy. The first Song Emperor created political institutions that allowed a great deal of freedom of discourse and thought, which facilitated the growth of scientific advance, economic reforms, and achievements in arts and literature. Trade flourished both within China and overseas, and the encouragement of technology allowed the mints at Kaifeng and Hangzhou to gradually increase in production. In 1080, the mints of Emperor Shenzong had produced 5 billion coins (roughly 50 per Chinese citizen), and the first banknotes were produced in 1023. These coins were so durable that they would still be in use 700 years later, in the 18th century.

There were many famous inventors and early scientists in the Song Dynasty period. The statesman Shen Kuo is best known for his book known as the *Dream Pool Essays* (1088 AD). In it, he wrote of use for a drydock to repair boats, the navigational magnetic compass, and the discovery of the concept of true north (with magnetic declination towards the North Pole).

Shen Kuo also devised a geological theory for land formation, or geomorphology, and theorized that there was climate change in geological regions over an enormous span of time.

The equally talented statesman Su Song was best known for his engineering project of the AstronomicalClock Tower of Kaifeng, by 1088 AD. The clock tower was driven by a rotating waterwheel and escapement mechanism. Crowning the top of the clock tower was the large bronze, mechanically-driven, rotating armillary sphere.

In 1070, Su Song also compiled the *Ben Cao Tu Jing* (Illustrated Pharmacopoeia, original source material from 1058 to 1061 AD) with a team of scholars. This pharmaceutical treatise covered a wide range of other related subjects, including botany, zoology, mineralogy, and metallurgy.

Chinese astronomers were the first to record observations of a supernova, the first being the SN 185, recorded during the Han dynasty. Chinese astronomers made two more notable supernova observations during the Song Dynasty: the SN 1006, the brightest recorded supernova in history; and the SN 1054, making the Crab Nebula the first astronomical object recognized as being connected to a supernova explosion.

Archaeology

During the early half of the Song dynasty (960–1279), the study of archaeology developed out of the antiquarian interests of the educated gentry and their desire to revive the use of ancient vessels in state rituals and ceremonies. This and the belief that ancient vessels were products of 'sages' and not common people was criticized by Shen Kuo, who took an interdisciplinary approach to archaeology, incorporating his archaeological findings into studies on metallurgy, optics, astronomy, geometry, and ancient music measures.

His contemporary Ouyang Xiu (1007–1072) compiled an analytical catalogue of ancient rubbings on stone and bronze, which Patricia B. Ebrey says pioneered ideas in early epigraphy and archaeology. In accordance with the beliefs of the later Leopold von Ranke (1795–1886), some Song gentry—such as Zhao Mingcheng (1081–1129)—supported the primacy of contemporaneous archaeological finds of ancient inscriptions over historical works written after the fact, which they contested to be unreliable in regard to the former evidence. Hong Mai (1123–1202) used ancient Han Dynasty era vessels to debunk what he found to be fallacious descriptions of Han vessels in the *Bogutu* archaeological catalogue compiled during the latter half of Huizong's reign (1100–1125).

Geology and climatology

In addition to his studies in meteorology, astronomy, and archaeology mentioned above, Shen Kuo also made hypotheses in regards to geology and climatology in his *Dream Pool Essays* of 1088, specifically his claims regarding geomorphology and climate change. Shen believed that land was reshaped over time due to perpetual erosion, uplift, and deposition of silt, and cited his observance of horizontal strata of fossils embedded in a cliffside at Taihang as evidence that the area was once the location of an ancient seashore that had shifted hundreds of miles east over an enormous span of time. Shen also wrote that since petrified bamboos were found underground in a dry northern climate zone where they had never been known to grow, climates naturally shifted geographically over time.

Chemistry

Until the Song Dynasty, Chinese medicine classified drugs under the system of the *Zhenghe bencao* (Herbal of the Zhenghe Era):

- Superior drugs, associated with immortality, were used for the realization of vital powers
- Medium drugs that enrich one's nature
- Inferior drugs were those used to treat diseases

These early forms of drugs were made using primitive methods, usually just simple dried herbs, or unprocessed minerals. They were developed into combinations known as "elixirs of immortality". These early magical practices, supported by the imperial courts of Shihunagdi (259-210 BCE) and Emperor Wu (156-87 BCE) eventually led to the first observations of chemistry in ancient China. Chinese alchemists searched for ways to make cinnabar, gold and other minerals water soluble so they could be ingested, such as using a solution of potassium nitrate in vinegar . Solubilzation of cinnabar was found to occur only if an impurity (chlorideion) was present. Gold also was soluble when iodate was present in crude niter deposits.

Mongol transmission

Mongol rule under the Yuan dynasty saw technological advances from an economic perspective, with the first mass production of paper banknotes by Kublai Khan in the 13th century. Numerous contacts between Europe and the Mongols occurred in the 13th century, particularly through the unstable Franco-Mongol alliance. Chinese corps, expert in siege warfare, formed an integral part of the Mongol armies campaigning in the West. In 1259–1260 military alliance of the Franks knights of the ruler of Antioch, Bohemond VI and his father-in-law Hetoum I with the Mongols under Hulagu, in which they fought together for the conquests of Muslim Syria, taking together the city of Aleppo, and later Damascus. William of Rubruck, an ambassador to the Mongols in 1254–1255, a personal friend of Roger Bacon, is also often designated as a possible intermediary in the transmission of gunpowder know-how between the East and the West. The compass is often said to have been introduced by the Master of the Knights TemplarPierre de Montaigu between 1219 and 1223, from one of his travels to visit the Mongols in Persia.

Chinese and Arabic astronomy intermingled under Mongol rule. Muslim astronomers worked in the Chinese Astronomical Bureau established by Kublai Khan, while some Chinese astronomers also worked at the PersianMaragha observatory. Before this, in ancient times, Indian astronomers had lent their expertise to the Chinese court.

Theory and hypothesis

As Toby E. Huff notes, pre-modern Chinese science developed precariously without solid scientific theory, while there was a lacking of consistent systemic treatment in comparison to contemporaneous European works such as the *Concordance and Discordant Canons* by Gratian of Bologna (fl. 12th century). This drawback to Chinese science was lamented even by the mathematician Yang Hui (1238–1298), who criticized earlier mathematicians such as Li Chunfeng (602–670) who were content with using methods without working out their theoretical origins or principle, stating:

The men of old changed the name of their methods from problem to problem, so that as no specific explanation was given, there is no way of telling their theoretical origin or basis.

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Despite this, Chinese thinkers of the Middle Ages proposed some hypotheses which are in accordance with modern principles of science. Yang Hui provided theoretical proof for the proposition that the complements of the parallelograms which are about the diameter of any given parallelogram are equal to one another. Sun Sikong (1015–1076) proposed the idea that rainbows were the result of the contact between sunlight and moisture in the air, while Shen Kuo (1031–1095) expanded upon this with description of atmospheric refraction. Shen believed that rays of sunlight refracted before reaching the surface of the earth, hence the appearance of the observed sun from earth did not match its exact location. Coinciding with the astronomical work of his colleague Wei Pu, Shen and Wei realized that the old calculation technique for the mean sun was inaccurate compared to the apparent sun, since the latter was ahead of it in the accelerated phase of motion, and behind it in the retarded phase. Shen supported and expanded upon beliefs earlier proposed by Han dynasty (202 BCE–220 CE) scholars such as Jing Fang (78–37 BCE) and Zhang Heng (78–139 CE) that lunar eclipse occurs when the earth obstructs the sunlight traveling towards the moon, a solar eclipse is the moon's obstruction of sunlight reaching earth, the moon is spherical like a ball and not flat like a disc, and moonlight is merely sunlight reflected from the moon's surface. Shen also explained that the observance of a full moon occurred when the sun's light was slanting at a certain degree and that crescent phases of the moon proved that the moon was spherical, using a metaphor of observing different angles of a silver ball with white powder thrown onto one side. Although the Chinese accepted the idea of spherical-shaped heavenly bodies, the concept of a spherical earth (as opposed to a flat earth) was not accepted in Chinese thought until the works of Italian Jesuit Matteo Ricci (1552–1610) and Chinese astronomer Xu Guangqi (1562–1633) in the early 17th century.

Pharmacology

There were noted advances in traditional Chinese medicine during the Middle Ages. Emperor Gaozong (reigned 649–683) of the Tang dynasty (618–907) commissioned the scholarly compilation of a *materia medica* in 657 that documented 833 medicinal substances taken from stones, minerals, metals, plants, herbs, animals, vegetables, fruits, and cereal crops. In his *Bencao Tujing* ('Illustrated Pharmacopoeia'), the scholar-official Su Song (1020–1101) not only systematically categorized herbs and minerals according to their pharmaceutical uses, but he also took an interest in zoology. For example, Su made systematic descriptions of animal species and the environmental regions they could be found, such as the freshwater crab*Eriocher sinensis* found in the Huai River running through Anhui, in waterways near the capital city, as well as reservoirs and marshes of Hebei.

Muhammad ibn Zakariya al-Razi in 896, mentions the popular introduction of various Chineseherbs and aloes in Baghdad.

Horology and clockworks

Although the *Bencao Tujing* was an important pharmaceutical work of the age, Su Song is perhaps better known for his work in horology. His book *Xinyi Xiangfayao* (新儀象法要; lit. 'Essentials of a New Method for Mechanizing the Rotation of an Armillary Sphere and a Celestial Globe') documented the intricate mechanics of his astronomical clock tower in Kaifeng. This included the use of an escapement mechanism and world's first known chain drive to power the rotating armillary sphere crowning the top as well as the 133 clock jack figurines positioned on a rotating wheel that sounded the hours by banging drums, clashing gongs, striking bells, and holding plaques with special announcements appearing from open-and-close shutter windows. While it had been Zhang Heng who applied the first motive power to the armillary sphere via hydraulics in 125 CE, it was Yi Xing (683–727) in 725 CE who first applied an escapement mechanism to a water-powered celestial globe and striking clock. The early Song Dynasty horologist Zhang Sixun (fl. late 10th century) employed liquid mercury in his astronomical clock because there were complaints that water would freeze too easily in the clepsydra tanks during winter.

Al-Jazari (1136–1206), a Muslim engineer and inventor of various clocks, including the Elephant clock, wrote: "[T]he elephant represents the Indian and African cultures, the two dragons represents Chinese culture, the phoenix represents Persian culture, the water work represents ancient Greek culture, and the turban represents Islamic culture".

Magnetism and metallurgy

Shen Kuo's written work of 1088 also contains the first written description of the magnetic needle compass, the first description in China of experiments with camera obscura, the invention of movable type printing by the artisan Bi Sheng (990–1051), a method of repeated forging of cast iron under a cold blast similar to the modern Bessemer process, and the mathematical basis for spherical trigonometry that would later be mastered by the astronomer and engineer Guo Shoujing (1231–1316). While using a sighting tube of improved width to correct the position of the pole star (which had shifted over the centuries), Shen discovered the concept of true north and magnetic declination towards the North Magnetic Pole, a concept which would aid navigators in the years to come.

In addition to the method similar to the Bessemer process mentioned above, there were other notable advancements in Chinese metallurgy during the Middle Ages. During the 11th century, the growth of the iron industry caused vast deforestation due to the use of charcoal in the smelting process. To remedy the problem of deforestation, the Song Chinese discovered how to produce coke from bituminous coal as a substitute for charcoal. Although hydraulic-powered bellows for heating the blast furnace had been written of since Du Shi's (d. 38) invention of the 1st century CE, the first known drawn and printed illustration of it in operation is found in a book written in 1313 by Wang Zhen (fl. 1290–1333).

Mathematics

Qin Jiushao (c. 1202–1261) was the first to introduce the zero symbol into Chinese mathematics. Before this innovation, blank spaces were used instead of zeros in the system of counting rods. Pascal's triangle was first illustrated in China by Yang Hui in his book *Xiangjie Jiuzhang Suanfa* (详解九章算法), although it was described earlier around 1100 by Jia Xian. Although the *Introduction to Computational Studies* (算学启蒙) written by Zhu Shijie (fl. 13th century) in 1299 contained nothing new in Chinese algebra, it had a great impact on the development of Japanese mathematics.

Alchemy and Taoism

In their pursuit for an elixir of life and desire to create gold from various mixtures of materials, Taoists became heavily associated with alchemy. Joseph Needham labeled their pursuits as proto-scientific rather than merely pseudoscience. Fairbank and Goldman write that the futile experiments of Chinese alchemists did lead to the discovery of new metal alloys, porcelain types, and dyes. However, Nathan Sivin discounts such a close connection between Taoism and alchemy, which some sinologists have asserted, stating that alchemy was more prevalent in the secular sphere and practiced by laymen. Experimentation with various materials and ingredients in China during the middle period led to the discovery of many ointments, creams, and other mixtures with practical uses.

In a 9th-century Arab work *Kitāb al-Khawāss al Kabīr*, there are numerous products listed that were native to China, including waterproof and dust-repelling cream or varnish for clothes and weapons, a Chinese lacquer, varnish, or cream that protected leather items, a completely fire-proof cement for glass and porcelain, recipes for Chinese and Indian ink, a waterproof cream for the silk garments of underwater divers, and a cream specifically used for polishing mirrors.

Gunpowder warfare

The significant change that distinguished Medieval warfare to early Modern warfare was the use of gunpowder weaponry in battle. A 10th-century silken banner from Dunhuang portrays the first artistic depiction of a fire lance, a prototype of the gun. The *Wujing Zongyao* military manuscript of 1044 listed the first known written formulas for gunpowder, meant for light-weight bombs lobbed from catapults or thrown down from defenders behind city walls. By the 13th century, the iron-cased bomb shell, hand cannon, land mine, and rocket were developed. As evidenced by the *Huolongjing* of Jiao Yu and Liu Bowen, by the 14th century the Chinese had developed the heavy cannon, hollow and gunpowder-packed exploding cannonballs, the two-stage rocket with a booster rocket, the naval mine and wheellock mechanism to ignite trains of fuses.

Jesuit activity in China

The Jesuit China missions of the 16th and 17th centuries introduced Western science and astronomy, then undergoing its own revolution, to China. One modern historian writes that in late Ming courts, the Jesuits were "regarded as impressive especially for their knowledge of astronomy, calendar-making, mathematics, hydraulics, and geography." The Society of Jesus introduced, according to Thomas Woods, "a substantial body of scientific knowledge and a vast array of mental tools for understanding the physical universe, including the Euclidean geometry that made planetary motion comprehensible." Another expert quoted by Woods said the scientific revolution brought by the Jesuits coincided with a time when science was at a very low level in China:

[The Jesuits] made efforts to translate western mathematical and astronomical works into Chinese and aroused the interest of Chinese scholars in these sciences. They made very extensive astronomical observation and carried out the first modern cartographic work in China. They also learned to appreciate the scientific achievements of this ancient culture and made them known in Europe. Through their correspondence European scientists first learned about the Chinese science and culture.

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Johann Adam Schall published Yuan Jing Shuo, Explanation of the Telescope, in 1626, in Latin and Chinese. Schall's book referred to the telescopic observations of Galileo.

Conversely, the Jesuits were very active in transmitting Chinese knowledge to Europe. Confucius's works were translated into European languages through the agency of Jesuit scholars stationed in China. Matteo Ricci started to report on the thoughts of Confucius, and Father Prospero Intorcetta published the life and works of Confucius into Latin in 1687. It is thought that such works had considerable importance on European thinkers of the period, particularly among the Deists and other philosophical groups of the Enlightenment who were interested by the integration of the system of morality of Confucius into Christianity.

The followers of the French physiocratFrançois Quesnay habitually referred to him as "the Confucius of Europe", and he personally identified himself with the Chinese sage. The doctrine and even the name of "Laissez-faire" may have been inspired by the Chinese concept of Wu wei. However, the economic insights of ancient Chinese political thought had otherwise little impact outside China in later centuries. Goethe, was known as "the Confucius of Weimar".

Scientific and technological stagnation

One question that has been the subject of debate among historians has been why China did not develop a scientific revolution and why Chinese technology fell behind that of Europe. Many hypotheses have been proposed ranging from the cultural to the political and economic. John K. Fairbank, for example, argued that the Chinese political system was hostile to scientific progress. As for Needham, he wrote that cultural factors prevented traditional Chinese achievements from developing into what could be called "science." It was the religious and philosophical framework of the Chinese intellectuals which made them unable to believe in the ideas of laws of nature:

It was not that there was no order in nature for the Chinese, but rather that it was not an order ordained by a rational personal being, and hence there was no conviction that rational personal beings would be able to spell out in their lesser earthly languages the divine code of laws which he had decreed aforetime. The Taoists, indeed, would have scorned such an idea as being too naïve for the subtlety and complexity of the universe as they intuited it.

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Another prominent historian of science, Nathan Sivin, has argued that China indeed had a scientific revolution in the 17th century but it's just that we are still not able to really understand the scientific revolution that took place in China. Sivin suggests that we need to look at the scientific development in China on its own terms.

There are also questions about the philosophy behind traditional Chinese medicine, which, derived partly from Taoist philosophy, reflects the classical Chinese belief that individual human experiences express causative principles effective in the environment at all scales. Because its theory predates use of the scientific method, it has received various criticisms based on scientific thinking. Philosopher Robert Todd Carroll, a member of the Skeptics Society, deemed acupuncture a pseudoscience because it "confuse(s) metaphysical claims with empirical claims".

More recent historians have questioned political and cultural explanations and have put greater focus on economic causes. Mark Elvin's high level equilibrium trap is one well-known example of this line of thought. It argues that the Chinese population was large enough, workers cheap enough, and agrarian productivity high enough to not require mechanization: thousands of Chinese workers were perfectly able to quickly perform any needed task. Other events such as Haijin, the Opium Wars and the resulting hate of European influence prevented China from undergoing an Industrial Revolution; copying Europe's progress on a large scale would be impossible for a lengthy period of time. Political instability under Cixi rule (opposition and frequent oscillation between modernists and conservatives), the Republican wars (1911–1933), the Sino-Japanese War (1933–1945), the Communist/Nationalist War (1945–1949) as well as the later Cultural Revolution isolated China at the most critical times. Kenneth Pomeranz has made the argument that the substantial resources taken from the New World to Europe made the crucial difference between European and Chinese development.

In his book *Guns, Germs, and Steel*, Jared Diamond postulates that the lack of geographic barriers within much of China—essentially a wide plain with two large navigable rivers and a relatively smooth coastline—led to a single government without competition. At the whim of a ruler who disliked new inventions, technology could be stifled for half a century or more. In contrast, Europe's barriers of the Pyrenees, the Alps, and the various defensible peninsulas (Denmark, Scandinavia, Italy, Greece, etc.) and islands (Britain, Ireland, Sicily, etc.) led to smaller countries in constant competition with each other. If a ruler chose to ignore a scientific advancement (especially a military or economic one), his more-advanced neighbors would soon usurp his throne. This explanation, however, ignores the fact that China had beenpolitically fragmentedin the past, and was thus not inherently disposed to political unification.

The Republic of China (1912–49)

The Republic of China (1912–49) saw the introduction in earnest of modern science to China. Large numbers of Chinese students studied abroad in Japan and in Europe and the US. Many returned to help teach and to found numerous schools and universities. Among them were numerous outstanding figures, including Cai Yuanpei, Hu Shih, Weng Wenhao, Ding Wenjiang, Fu Ssu-nien, and many others. As a result, there was a tremendous growth of modern science in China. As the Communist Party took over China's mainland in 1949, some of these Chinese scientists and institutions moved to Taiwan. The central science academy, Academia Sinica, also moved there.

People's Republic of China

After the establishment of the People's Republic in 1949, China reorganized its science establishment along Soviet lines. Although the country regressed scientifically as a result of government policies which led to famine during the Great Leap Forward and political chaos during the Cultural Revolution, scientific research in nuclear weapons and satellite launching still gained great success. From 1975, science and technology was one of the Four Modernizations, and its high-speed development was declared essential to all national economic development by Deng Xiaoping. Other civilian technologies such as superconductivity and high-yield hybrid rice led to new developments due to the application of science to industry and foreign technology transfer.

As the People's Republic of China becomes better connected to the global economy, the government has placed more emphasis on science and technology. This has led to increases in funding, improved scientific structure, and more money for research. These factors have led to advancements in agriculture, medicine, genetics, and global change. In 2003, the Chinese space program allowed China to become the third country to send humans into space, and ambition to put a man on mars by 2030. In the 2000s and 2010s, China became a top scientific and industrial power in more advanced fields such as super computing, artificial intelligence, bullet trains, aeronautics, nuclear physics researches and other fields.

In 2016, China became the country with the highest science output, as measured in publications. While the US had been the biggest producer of scientific studies until then, China published 426,000 studies in 2016 while the US published 409,000. However, the numbers are somewhat relative, as it also depends how authorship on international collaborations is counted (e.g. if one paper is counted per person or whether authorship is split among authors).

Chapter 8

History of Technology in the India

The history of science and technology in the Indian subcontinent begins with prehistoric human activity in the Indus Valley Civilization to early states and empires. Following independence, science and technology in the Republic of India has included automobile engineering, information technology, communications as well as space, polar, and nuclear sciences.

Prehistory

By 5500 BCE a number of sites similar to Mehrgarh had appeared, forming the basis of later chalcolithic cultures. The inhabitants of these sites maintained trading relations with Near East and Central Asia.

Irrigation was developed in the Indus Valley Civilization by around 4500 BCE. The size and prosperity of the Indus civilization grew as a result of this innovation, which eventually led to more planned settlements making use of drainage and sewerage. Sophisticated irrigation and water storage systems were developed by the Indus Valley Civilization, including artificial reservoirs at Girnar dated to 3000 BCE, and an early canal irrigation system from c. 2600 BCE. Cotton was cultivated in the region by the 5th–4th millennia BCE. Sugarcane was originally from tropical South and Southeast Asia. Different species likely originated in different locations with *S. barberi* originating in India, and *S. edule* and *S. officinarum* coming from New Guinea.

The inhabitants of the Indus valley developed a system of standardization, using weights and measures, evident by the excavations made at the Indus valley sites. This technical standardization enabled gauging devices to be effectively used in angular measurement and measurement for construction. Calibration was also found in measuring devices along with multiple subdivisions in case of some devices. One of the earliest known docks is at Lothal (2400 BCE), located away from the main current to avoid deposition of silt. Modern oceanographers have observed that the Harappans must have possessed knowledge relating to tides in order to build such a dock on the ever-shifting course of the Sabarmati, as well as exemplary hydrography and maritime engineering.

- Excavations at Balakot (c. 2500–1900 BCE), present day Pakistan, have yielded evidence of an early furnace. The furnace was most likely used for the manufacturing of ceramic objects. Ovens, dating back to the civilization's mature phase (c. 2500–1900 BCE), were also excavated at Balakot. The Kalibangan archeological site further yields evidence of potshaped hearths, which at one site have been found both on ground and underground. Kilns with fire and kiln chambers have also been found at the Kalibangan site.

Based on archaeological and textual evidence, Joseph E. Schwartzberg (2008)—a University of Minnesotaprofessor emeritus of geography—traces the origins of Indian cartography to the Indus Valley Civilization (c. 2500–1900 BCE). The use of large scale constructional plans, cosmological drawings, and cartographic material was known in India with some regularity since the Vedic period (2nd – 1st millennium BCE). Climatic conditions were responsible for the destruction of most of the evidence, however, a number of excavated surveying instruments and measuring rods have yielded convincing evidence of early cartographic activity. Schwartzberg (2008)—on the subject of surviving maps—further holds that: 'Though not numerous, a number of map-like graffiti appear among the thousands of Stone Age Indian cave paintings; and at least one complex Mesolithic diagram is believed to be a representation of the cosmos.'

Archeological evidence of an animal-drawn plough dates back to 2500 BCE in the Indus Valley Civilization. The earliest available swords of copper discovered from the Harappan sites date back to 2300 BCE. Swords have been recovered in archaeological findings throughout the Ganges–JamunaDoab region of India, consisting of bronze but more commonly copper.

Early kingdoms

- The religious texts of the Vedic Period provide evidence for the use of large numbers. By the time of the last Veda, the *Yajurvedasaṃhitā* (1200–900 BCE),

  numbers as high as were being included in the texts. For example, the *mantra* (sacrificial formula) at the end of the *annahoma* ("food-oblation rite") performed during the *aśvamedha* ("an allegory for a horse sacrifice"), and uttered just before-, during-, and just after sunrise, invokes powers of ten from a hundred to a trillion. The Satapatha Brahmana (9th century BCE) contains rules for ritual geometric constructions that are similar to the Sulba Sutras.

The earliest Indian astronomical text—named *Vedānga Jyotiṣa* and attributed to *Lagadha*—is considered one of the oldest astronomical texts, dating from 1400–1200 BCE (with the extant form possibly from 700–600 BCE), it details several astronomical attributes generally applied for timing social and religious events. It also details astronomical calculations, calendrical studies, and establishes rules for empirical observation. Since the *Vedānga Jyotiṣa* is a religious text, it has connections with Indian astrology and details several important aspects of the time and seasons, including lunar months, solar months, and their adjustment by a lunar leap month of *Adhikamāsa. Ritus* and *Yugas* are also described. Tripathi (2008) holds that "Twenty-seven constellations, eclipses, seven planets, and twelve signs of the zodiac were also known at that time."

The Egyptian*Papyrus of Kahun* (1900 BCE) and literature of the Vedic period in India offer early records of veterinary medicine. Kearns & Nash (2008) state that mention of leprosy is described in the medical treatise *Sushruta Samhita* (6th century BCE). The Sushruta Samhita an Ayurvedic text contains 184 chapters and description of 1120 illnesses, 700 medicinal plants, a detailed study on Anatomy, 64 preparations from mineral sources and 57 preparations based on animal sources. However, *The Oxford Illustrated Companion to Medicine* holds that the mention of leprosy, as well as ritualistic cures for it, were described in the Hindu religious book *Atharva-veda*, written in 1500–1200 BCE.

Cataract surgery was known to the physician Sushruta (6th century BCE). Traditional cataract surgery was performed with a special tool called the *Jabamukhi Salaka*, a curved needle used to loosen the lens and push the cataract out of the field of vision. The eye would later be soaked with warm butter and then bandaged. Though this method was successful, Susruta cautioned that it should only be used when necessary. The removal of cataract by surgery was also introduced into China from India.

During the 5th century BCE, the scholar Pāṇini had made several discoveries in the fields of phonetics, phonology, and morphology. Pāṇini's morphological analysis remained more advanced than any equivalent Western theory until the mid-20th century. Metalcurrency was minted in India before the 5th century BCE, with coinage (400 BCE–100 CE) being made of silver and copper, bearing animal and plant symbols on them.

Zinc mines of Zawar, near Udaipur, Rajasthan, were active during 400 BCE. Diverse specimens of swords have been discovered in Fatehgarh, where there are several varieties of hilt. These swords have been variously dated to periods between 1700–1400 BCE, but were probably used more extensively during the opening centuries of the 1st millennium BCE. Archaeological sites in such as Malhar, Dadupur, Raja Nala Ka Tila and Lahuradewa in present-day Uttar Pradesh show iron implements from the period between 1800 BCE and 1200 BCE. Early iron objects found in India can be dated to 1400 BCE by employing the method of radio carbon dating. Some scholars believe that by the early 13th century BCE iron smelting was practiced on a bigger scale in India, suggesting that the date of the technology's inception may be placed earlier. In Southern India (present day Mysore) iron appeared as early as 11th to 12th centuries BCE. These developments were too early for any significant close contact with the northwest of the country.

Middle Kingdoms (230 BCE – 1206 CE)

The *Arthashastra* of Kautilya mentions the construction of dams and bridges. The use of suspension bridges using plaited bamboo and iron chain was visible by about the 4th century. The *stupa*, the precursor of the pagoda and torii, was constructed by the 3rd century BCE. Rock-cut step wells in the region date from 200–400 CE. Subsequently, the construction of wells at Dhank (550–625 CE) and stepped ponds at Bhinmal (850–950 CE) took place.

During the 1st millennium BCE, the Vaisheshikaschool of atomism was founded. The most important proponent of this school was Kanada, an Indian philosopher who lived around 600 BCE. The school proposed that atoms are indivisible and eternal, can neither be created nor destroyed, and that each one possesses its own distinct *viśeṣa* (individuality).

It was further elaborated on by the Buddhist school of atomism, of which the philosophers Dharmakirti and Dignāga in the 7th century CE were the most important proponents. They considered atoms to be point-sized, durationless, and made of energy.

By the beginning of the Common Era glass was being used for ornaments and casing in the region. Contact with the Greco-Roman world added newer techniques, and local artisans learnt methods of glass molding, decorating and coloring by the early centuries of the Common Era. The Satavahana period further reveals short cylinders of composite glass, including those displaying a lemon yellow matrix covered with green glass. Wootz originated in the region before the beginning of the common era. Wootz was exported and traded throughout Europe, China, the Arab world, and became particularly famous in the Middle East, where it became known as Damascus steel. Archaeological evidence suggests that manufacturing process for Wootz was also in existence in South India before the Christian era.

Evidence for using bow-instruments for carding comes from India (2nd century CE). The mining of diamonds and its early use as gemstones originated in India. Golconda served as an important early center for diamond mining and processing. Diamonds were then exported to other parts of the world. Early reference to diamonds comes from Sanskrit texts. The *Arthashastra* also mentions diamond trade in the region. The Iron pillar of Delhi was erected at the times of Chandragupta II Vikramaditya (375–413), which stood without rusting for around 2 millennium. The Rasaratna Samuccaya (800) explains the existence of two types of ores for zinc metal, one of which is ideal for metal extraction while the other is used for medicinal purpose.

The origins of the spinning wheel are unclear but India is one of the probable places of its origin. The device certainly reached Europe from India by the 14th century. The cotton gin was invented in India as a mechanical device known as *charkhi*, the "wooden-worm-worked roller". This mechanical device was, in some parts of the region, driven by water power. The Ajanta Caves yield evidence of a single roller cotton gin in use by the 5th century. This cotton gin was used until further innovations were made in form of foot powered gins. Chinese documents confirm at least two missions to India, initiated in 647, for obtaining technology for sugar-refining. Each mission returned with different results on refining sugar. Pingala (300–200 BCE) was a musical theorist who authored a Sanskrit treatise on prosody. There is evidence that in his work on the enumeration of syllabic combinations, Pingala stumbled upon both the Pascal triangle and Binomial coefficients, although he did not have knowledge of the Binomial theorem itself. A description of binary numbers is also found in the works of Pingala. The Indians also developed the use of the law of signs in multiplication. Negative numbers and the subtrahend had been used in East Asia since the 2nd century BCE, and Indian mathematicians were aware of negative numbers by the 7th century CE, and their role in mathematical problems of debt was understood. Although the Indians were not the first to use the subtrahend, they were the first to establish the "law of signs" with regards to the multiplication of positive and negative numbers, which did not appear in East Asian texts until 1299. Mostly consistent and correct rules for working with negative numbers were formulated, and the diffusion of these rules led the Arab intermediaries to pass it on to Europe.

A decimal number system using hieroglyphics dates back to 3000 BC in Egypt, and was later in use in ancient India. By the 9th century CE, the Hindu–Arabic numeral system was transmitted from the Middle East and to the rest of the world.

The concept of 0 as a number, and not merely a symbol for separation is attributed to India. In India, practical calculations were carried out using zero, which was treated like any other number by the 9th century CE, even in case of division. Brahmagupta (598–668) was able to find (integral) solutions of Pell's equation. Conceptual design for a perpetual motion machine by Bhaskara II dates to 1150. He described a wheel that he claimed would run forever.

The trigonometric functions of sine and versine, from which it was trivial to derive the cosine, were used by the mathematician, Aryabhata, in the late 5th century. The calculus theorem now known as "Rolle's theorem" was stated by mathematician, Bhāskara II, in the 12th century.

Indigo was used as a dye in India, which was also a major center for its production and processing. The *Indigofera tinctoria* variety of Indigo was domesticated in India. Indigo, used as a dye, made its way to the Greeks and the Romans via various trade routes, and was valued as a luxury product. The cashmere wool fiber, also known as *pashm* or *pashmina*, was used in the handmade shawls of Kashmir. The woolen shawls from Kashmir region find written mention between 3rd century BCE and the 11th century CE. Crystallized sugar was discovered by the time of the Gupta dynasty, and the earliest reference to candied sugar comes from India. Jute was also cultivated in India. Muslin was named after the city where Europeans first encountered it, Mosul, in what is now Iraq, but the fabric actually originated from Dhaka in what is now Bangladesh. In the 9th century, an Arab merchant named Sulaiman makes note of the material's origin in Bengal (known as *Ruhml* in Arabic).

European scholar Francesco Lorenzo Pullè reproduced a number of Indian maps in his magnum opus *La Cartografia Antica dell India*. Out of these maps, two have been reproduced using a manuscript of *Lokaprakasa*, originally compiled by the polymath Ksemendra (Kashmir, 11th century CE), as a source. The other manuscript, used as a source by Francesco I, is titled *Samgraha'*.

Samarangana Sutradhara, a Sanskrit treatise by Bhoja (11th century), includes a chapter about the construction of mechanical contrivances (automata), including mechanical bees and birds, fountains shaped like humans and animals, and male and female dolls that refilled oil lamps, danced, played instruments, and re-enacted scenes from Hindu mythology.