The identification of the history of technology with the history of humanlike species does not help in fixing a precise point for its origin, because the estimates of prehistorians and anthropologists concerning the emergence of human species vary so widely. Animals occasionally use natural tools such as sticks or stones, and the creatures that became human doubtless did the same for hundreds of millennia before the first giant step of fashioning their own tools. Even then it was an interminable time before they put such toolmaking on a regular basis, and still more aeons passed as they arrived at the successive stages of standardizing their simple stone choppers and pounders and of manufacturing them—that is, providing sites and assigning specialists to the work. A degree of specialization in toolmaking was achieved by the time of the Neanderthals (, bce); more-advanced tools, requiring assemblage of head and haft, were produced by Cro-Magnons (perhaps as early as , bce); while the application of mechanical principles was achieved by pottery-making Neolithic (New Stone Age;  bce) and Metal Age peoples (about  bce).

Earliest communities

For all except approximately the past , years, humans lived almost entirely in small nomadic communities dependent for survival on their skills in gathering food, hunting and fishing, and avoiding predators. It is reasonable to suppose that most of these communities developed in tropical latitudes, especially in Africa, where climatic conditions are most favourable to a creature with such poor bodily protection as humans have. It is also reasonable to suppose that tribes moved out thence into the subtropical regions and eventually into the landmass of Eurasia, although their colonization of this region must have been severely limited by the successive periods of glaciation, which rendered large parts of it inhospitable and even uninhabitable, even though humankind has shown remarkable versatility in adapting to such unfavourable conditions.

The Neolithic Revolution

Toward the end of the last ice age, some , to , years ago, a few of the communities that were most favoured by geography and climate began to make the transition from the long period of Paleolithic, or Old Stone Age, lifestyles to a more settled way of life depending on animal husbandry and agriculture. This period of transition, the Neolithic Period, or New Stone Age, led eventually to a marked rise in population, to a growth in the size of communities, and to the beginnings of town life. It is sometimes referred to as the Neolithic Revolution because the speed of technological innovation increased so greatly and human social and political organization underwent a corresponding increase in complexity. To understand the beginnings of technology, it is thus necessary to survey developments from the Old Stone Age through the New Stone Age down to the emergence of the first urban civilizations about  bce.

Stone

The material that gives its name and a technological unity to these periods of prehistory is stone. Though it may be assumed that primitive humans used other materials such as wood, bone, fur, leaves, and grasses before they mastered the use of stone, apart from bone antlers, presumably used as picks in flint mines and elsewhere, and other fragments of bone implements, none of these has survived. The stone tools of early humans, on the other hand, have survived in surprising abundance, and over the many millennia of prehistory important advances in technique were made in the use of stone. Stones became tools only when they were shaped deliberately for specific purposes, and, for this to be done efficiently, suitable hard and fine-grained stones had to be found and means devised for shaping them and particularly for putting a cutting edge on them. Flint became a very popular stone for this purpose, although fine sandstones and certain volcanic rocks were also widely used. There is much Paleolithic evidence of skill in flaking and polishing stones to make scraping and cutting tools. These early tools were held in the hand, but gradually ways of protecting the hand from sharp edges on the stone, at first by wrapping one end in fur or grass or setting it in a wooden handle, were devised. Much later the technique of fixing the stone head to a haft converted these hand tools into more versatile tools and weapons.

Neolithic cutlery and foodstuffsNeolithic millstones, charred bread, grains and small apples, a clay cooking pot, and containers made of antlers and wood in the Bern Historical Museum in Switzerland.(more)

With the widening mastery of the material world in the Neolithic Period, other substances were brought into service, such as clay for pottery and brick, and increasing competence in handling textile raw materials led to the creation of the first woven fabrics to take the place of animal skins. About the same time, curiosity about the behaviour of metallic oxides in the presence of fire promoted one of the most significant technological innovations of all time and marked the succession from the Stone Age to the Metal Age.

Power

The use of fire was another basic technique mastered at some unknown time in the Old Stone Age. The discovery that fire could be tamed and controlled and the further discovery that a fire could be generated by persistent friction between two dry wooden surfaces were momentous. Fire was the most important contribution of prehistory to power technology, although little power was obtained directly from fire except as defense against wild animals. For the most part, prehistoric communities remained completely dependent upon manpower, but, in making the transition to a more settled pattern of life in the New Stone Age, they began to derive some power from animals that had been domesticated. It also seems likely that by the end of prehistoric times the sail had emerged as a means of harnessing the wind for small boats, beginning a long sequence of developments in marine transport.

Tools and weapons

The basic tools of prehistoric peoples were determined by the materials at their disposal. But once they had acquired the techniques of working stone, they were resourceful in devising tools and weapons with points and barbs. Thus, the stone-headed spear, the harpoon, and the arrow all came into widespread use. The spear was given increased impetus by the spear-thrower, a notched pole that gave a sling effect. The bow and arrow were an even more effective combination, the use of which is clearly demonstrated in the earliest “documentary” evidence in the history of technology, the cave paintings of southern France and northern Spain, which depict the bow being used in hunting. The ingenuity of these hunters is also shown in their slings, throwing-sticks (the boomerang of Australian Aboriginal people is a remarkable surviving example), blowguns, bird snares, fish and animal traps, and nets. These tools did not evolve uniformly, as each community developed only those instruments that were most suitable for its own specialized purposes, but all were in use by the end of the Stone Age. In addition, the Neolithic Revolution had contributed some important new tools that were not primarily concerned with hunting. These were the first mechanical applications of rotary action in the shape of the potter’s wheel, the bow drill, the pole lathe, and the wheel itself. It is not possible to be sure when these significant devices were invented, but their presence in the early urban civilizations suggests some continuity with the late Neolithic Period. The potter’s wheel, driven by kicks from the operator, and the wheels of early vehicles both gave continuous rotary movement in one direction. The drill and the lathe, on the other hand, were derived from the bow and had the effect of spinning the drill piece or the workpiece first in one direction and then in the other.

Developments in food production brought further refinements in tools. The processes of food production in Paleolithic times were simple, consisting of gathering, hunting, and fishing. If these methods proved inadequate to sustain a community, it moved to better hunting grounds or perished. With the onset of the Neolithic Revolution, new food-producing skills were devised to serve the needs of agriculture and animal husbandry. Digging sticks and the first crude plows, stone sickles, querns that ground grain by friction between two stones and, most complicated of all, irrigation techniques for keeping the ground watered and fertile—all these became well established in the great subtropical river valleys of Egypt and Mesopotamia in the millennia before  bce.

Building techniques

StonehengeA view from above the ruins of Stonehenge shows the arrangement of its ancient stones.

Prehistoric building techniques also underwent significant developments in the Neolithic Revolution. Nothing is known of the building ability of Paleolithic peoples beyond what can be inferred from a few fragments of stone shelters, but in the New Stone Age some impressive structures were erected, primarily tombs and burial mounds and other religious edifices, but also, toward the end of the period, domestic housing in which sun-dried brick was first used. In northern Europe, where the Neolithic transformation began later than around the eastern Mediterranean and lasted longer, huge stone monuments, of which Stonehenge in England is the outstanding example, still bear eloquent testimony to the technical skill, not to mention the imagination and mathematical competence, of the later Stone Age societies.

Manufacturing

Manufacturing industry had its origin in the New Stone Age, with the application of techniques for grinding corn, baking clay, spinning and weaving textiles, and also, it seems likely, for dyeing, fermenting, and distilling. Some evidence for all these processes can be derived from archaeological findings, and some of them at least were developing into specialized crafts by the time the first urban civilizations appeared. In the same way, the early metalworkers were beginning to acquire the techniques of extracting and working the softer metals, gold, silver, copper, and tin, that were to make their successors a select class of craftsmen. All these incipient fields of specialization, moreover, implied developing trade between different communities and regions, and again the archaeological evidence of the transfer of manufactured products in the later Stone Age is impressive. Flint arrowheads of particular types, for example, can be found widely dispersed over Europe, and the implication of a common locus of manufacture for each is strong.

Such transmission suggests improving facilities for transport and communication. Paleolithic people presumably depended entirely on their own feet, and this remained the normal mode of transport throughout the Stone Age. Domestication of the ox, the donkey, and the camel undoubtedly brought some help, although difficulties in harnessing the horse long delayed its effective use. The dugout canoe and the birch-bark canoe demonstrated the potential of water transport, and, again, there is some evidence that the sail had already appeared by the end of the New Stone Age.

It is notable that the developments so far described in human prehistory took place over a long period of time, compared with the , years of recorded history, and that they took place first in very small areas of Earth’s surface and involved populations minute by modern criteria. The Neolithic Revolution occurred first in those parts of the world with an unusual combination of qualities: a warm climate, encouraging rapid crop growth, and an annual cycle of flooding that naturally regenerated the fertility of the land. On the Eurasian-African landmass such conditions occur only in Egypt, Mesopotamia, northern India, and some of the great river valleys of China. It was there, then, that men and women of the New Stone Age were stimulated to develop and apply new techniques of agriculture, animal husbandry, irrigation, and manufacture, and it was there that their enterprise was rewarded by increasing productivity, which encouraged the growth of population and triggered a succession of sociopolitical changes that converted the settled Neolithic communities into the first civilizations. Elsewhere the stimulus to technological innovation was lacking or was unrewarded, so that those areas had to await the transmission of technical expertise from the more highly favoured areas. Herein is rooted the separation of the great world civilizations, for while the Egyptian and Mesopotamian civilizations spread their influence westward through the Mediterranean and Europe, those of India and China were limited by geographical barriers to their own hinterlands, which, although vast, were largely isolated from the mainstream of Western technological progress.

The urban revolution (c. – bce)

ziggurat at UrZiggurat at Ur (modern Tall al-Muqayyar, Iraq).

The technological change so far described took place very slowly over a long period of time, in response to only the most basic social needs, the search for food and shelter, and with few social resources available for any activity other than the fulfillment of these needs. About , years ago, however, a momentous cultural transition began to take place in a few well-favoured geographical situations. It generated new needs and resources and was accompanied by a significant increase in technological innovation. It was the beginning of the invention of the city.

Craftsmen and scientists

copper finialCopper finial showing a stag and two steers, from Alaca Hüyük, c. – bce; in the Archaeological Museum, Ankara, Turkey.(more)

The accumulated agricultural skill of the New Stone Age had made possible a growth in population, and the larger population in turn created a need for the products of specialized craftsmen in a wide range of commodities. These craftsmen included a number of metalworkers, first those treating metals that could be easily obtained in metallic form and particularly the soft metals, such as gold and copper, which could be fashioned by beating. Then came the discovery of the possibility of extracting certain metals from the ores in which they generally occur. Probably the first such material to be used was the carbonate of copper known as malachite, then already in use as a cosmetic and easily reduced to copper in a strong fire. It is impossible to be precise about the time and place of this discovery, but its consequences were tremendous. It led to the search for other metallic ores, to the development of metallurgy, to the encouragement of trade in order to secure specific metals, and to the further development of specialist skills. It contributed substantially to the emergence of urban societies, as it relied heavily upon trade and manufacturing industries, and thus to the rise of the first civilizations. The Stone Age gave way to the early Metal Age, and a new epoch in the story of humankind had begun.

By fairly general consent, civilization consists of a large society with a common culture, settled communities, and sophisticated institutions, all of which presuppose a mastery of elementary literacy and numeration. Mastery of the civilized arts was a minority pursuit in the early civilizations, in all probability the carefully guarded possession of a priestly caste. The very existence of these skills, however, even in the hands of a small minority of the population, is significant because they made available a facility for recording and transmitting information that greatly enlarged the scope for innovation and speculative thought.

Hitherto, technology had existed without the benefit of science, but, by the time of the first Sumerian astronomers, who plotted the motion of the heavenly bodies with remarkable accuracy and based calculations about the calendar and irrigation systems upon their observations, the possibility of a creative relationship between science and technology had appeared. The first fruits of this relationship appeared in greatly improved abilities to measure land, weigh, and keep time, all practical techniques, essential to any complex society, and inconceivable without literacy and the beginnings of scientific observation. With the emergence of these skills in the rd millennium bce, the first civilizations arose in the valleys of the Nile and of the Tigris-Euphrates.

Copper and bronze

The fact that the era of the early civilizations coincides with the technological classification of the Copper Age and Bronze Age is a clue to the technological basis of these societies. The softness of copper, gold, and silver made it inevitable that they should be the first to be worked, but archaeologists now seem to agree that there was no true “Copper Age” except perhaps for a short period at the beginning of Egyptian civilization, because the very softness of that metal limited its utility for everything except decoration or coinage. Attention was thus given early to means of hardening copper to make satisfactory tools and weapons. The reduction of mixed metallic ores probably led to the discovery of alloying, whereby copper was fused with other metals to make bronze. Several bronzes were made, including some containing lead, antimony, and arsenic, but by far the most popular and widespread was that of copper and tin in proportions of about to one. This was a hard yellowish metal that could be melted and cast into the shape required. The bronzesmiths took over from the coppersmiths and goldsmiths the technique of heating the metal in a crucible over a strong fire and casting it into simple clay or stone molds to make ax-heads or spearheads or other solid shapes. For the crafting of hollow vessels or sculpture, they devised the so-called cire perdue technique, in which the shape to be molded is formed in wax and set in clay, the wax then being melted and drained out to leave a cavity into which the molten metal is poured.

Horus falconHorus falcon wearing a double crown, bronze and gold sculpture, Egypt, c. – bce; in the Brooklyn Museum, New York.(more)

Bronze became the most important material of the early civilizations, and elaborate arrangements were made to ensure a continuous supply of it. Metals were scarce in the alluvial river valleys where civilization developed and therefore had to be imported. This need led to complicated trading relationships and mining operations at great distances from the homeland. Tin presented a particularly severe problem, as it was in short supply throughout the Middle East. The Bronze Age civilizations were compelled to search far beyond their own frontiers for sources of the metal, and in the process knowledge of the civilized arts was gradually transmitted westward along the developing Mediterranean trade routes.

Egyptian shipDrawing of an Egyptian seagoing ship, c.  bce, based on vessels depicted in the bas-relief discovered in the pyramid of King Sahure at Abū Ṣīr, Cairo.(more)

In most aspects other than the use of metals, the transition from the technology of the New Stone Age to that of early civilizations was fairly gradual, although there was a general increase in competence as specialized skills became more clearly defined, and in techniques of building there were enormous increases in the scale of enterprises. There were no great innovations in power technology, but important improvements were made in the construction of furnaces and kilns in response to the requirements of the metalworkers and potters and of new artisans such as glassworkers. Also, the sailing ship assumed a definitive shape, progressing from a vessel with a small sail rigged in its bows and suitable only for sailing before the prevailing wind up the Nile River, into the substantial oceangoing ship of the later Egyptian dynasties, with a large rectangular sail rigged amidships. Egyptian and Phoenician ships of this type could sail before the wind and across the wind, but for making headway into the wind they had to resort to manpower. Nevertheless, they accomplished remarkable feats of navigation, sailing the length of the Mediterranean and even passing through the Pillars of Hercules into the Atlantic.

Irrigation

of

Fertile CrescentThe Fertile Crescent includes the river valleys of the Nile and of the Tigris and Euphrates.

of

Egyptian shadoofEgyptian shadoof in Apuy's House and Garden, tempera reproduction of a wall painting, c.  bce, from the tomb of Apuy, Thebes; in the Metropolitan Museum of Art, New York City.(more)

Techniques of food production also showed many improvements over Neolithic methods, including one outstanding innovation in the shape of systematic irrigation. The civilizations of Egypt and Mesopotamia depended heavily upon the two great river systems, the Nile and the Tigris-Euphrates, which both watered the ground with their annual floods and rejuvenated it with the rich alluvium they deposited. The Nile flooded with regularity each summer, and the civilizations building in its valley early learned the technique of basin irrigation, ponding back the floodwater for as long as possible after the river had receded, so that enriched soil could bring forth a harvest before the floods of the following season. In the Tigris-Euphrates valley the irrigation problem was more complex, because the floods were less predictable, more fierce, and came earlier than those of the northward-flowing Nile. They also carried more alluvium, which tended to choke irrigation channels. The task of the Sumerian irrigation engineers was that of channeling water from the rivers during the summer months, impounding it, and distributing it to the fields in small installments. The Sumerian system eventually broke down because it led to an accumulation of salt in the soil, with a consequent loss of fertility. Both systems, however, depended on a high degree of social control, requiring skill in measuring and marking out the land and an intricate legal code to ensure justice in the distribution of precious water. Both systems, moreover, depended on intricate engineering in building dikes and embankments, canals and aqueducts (with lengthy stretches underground to prevent loss by evaporation), and the use of water-raising devices such as the shadoof, a balanced beam with a counterweight on one end and a bucket to lift the water on the other.

Urban manufacturing

Manufacturing industry in the early civilizations concentrated on such products as pottery, wines, oils, and cosmetics, which had begun to circulate along the incipient trade routes before the introduction of metals; these became the commodities traded for the metals. In pottery, the potter’s wheel became widely used for spinning the clay into the desired shape, but the older technique of building pots by hand from rolls of clay remained in use for some purposes. In the production of wines and oils various forms of press were developed, while the development of cooking, brewing, and preservatives justified the assertion that the science of chemistry began in the kitchen. Cosmetics too were an offshoot of culinary art.

Pack animals were still the primary means of land transport, the wheeled vehicle developing slowly to meet the divergent needs of agriculture, trade, and war. In the latter category, the chariot appeared as a weapon, even though its use was limited by the continuing difficulty of harnessing a horse. Military technology brought the development of metal plates for armour.

Building

Mari: zigguratZiggurat at Mari, Syria.

In building technology the major developments concerned the scale of operations rather than any particular innovation. The late Stone Age communities of Mesopotamia had already built extensively in sun-dried brick. Their successors continued the technique but extended its scale to construct the massive square temples called ziggurats. These had a core and facing of bricks, the facing walls sloping slightly inward and broken by regular pilasters built into the brickwork, the whole structure ascending in two or three stages to a temple on the summit. Sumerians were also the first to build columns with brick made from local clay, which also provided the writing material for the scribes.

pyramid of KhafrePyramid of Khafre, near Giza, Egypt.

In Egypt, clay was scarce but good building stone was plentiful, and builders used it in constructing the pyramids and temples that remain today as outstanding monuments of Egyptian civilization. Stones were pulled on rollers and raised up the successive stages of the structure by ramps and by balanced levers adapted from the water-raising shadoof. The stones were shaped by skilled masons, and they were placed in position under the careful supervision of priest-architects who were clearly competent mathematicians and astronomers, as is evident from the precise astronomical alignments. It seems certain that the heavy labour of construction fell upon armies of slaves, which helps to explain both the achievements and limitations of early civilizations. Slaves were usually one of the fruits of military conquest, which presupposes a period of successful territorial expansion, although their status as a subject race could be perpetuated indefinitely. Slave populations provided a competent and cheap labour force for the major constructional works that have been described. On the other hand, the availability of slave labour discouraged technological innovation, a social fact that goes far toward explaining the comparative stagnation of mechanical invention in the ancient world.

Transmitting knowledge

In the ancient world, technological knowledge was transmitted by traders, who went out in search of tin and other commodities, and by craftsmen in metal, stone, leather, and the other mediums, who passed their skills to others by direct instruction or by providing models that challenged other craftsmen to copy them. This transmission through intermediary contact was occurring between the ancient civilizations and their neighbours to the north and west during the nd millennium bce. The pace quickened in the subsequent millennium, distinct new civilizations arising in Crete and Mycenae, in Troy and Carthage. Finally, the introduction of the technique of working iron profoundly changed the capabilities and resources of human societies and ushered in the Classical civilizations of Greece and Rome.

Technological achievements of Greece and Rome ( bce– ce)

The contributions of Greece and Rome in philosophy and religion, political and legal institutions, poetry and drama, and in the realm of scientific speculation stand in spectacular contrast with their relatively limited contributions in technology. Their mechanical innovation was not distinguished, and, even in the realms of military and construction engineering, in which they showed great ingenuity and aesthetic sensibility, their work represented more a consummation of earlier lines of development than a dramatic innovation. This apparent paradox of the Classical period of the ancient world requires explanation, and the history of technology can provide some clues to the solution of the problem.

The mastery of iron

The outstanding technological factor of the Greco-Roman world was the smelting of iron, a technique—derived from unknown metallurgists, probably in Asia Minor, about  bce—that spread far beyond the provincial frontiers of the Roman Empire. The use of the metal had become general in Greece and the Aegean Islands by the dawn of the Classical period about  bce, and it appears to have spread quickly westward thereafter. Iron ore, long a familiar material, had defied reduction into metallic form because of the great heat required in the furnace to perform the chemical transformation (about , °C [, °F] compared with the , °C [, °F] necessary for the reduction of copper ores). To reach this temperature, furnace construction had to be improved and ways devised to maintain the heat for several hours. Throughout the Classical period these conditions were achieved only on a small scale, in furnaces burning charcoal and using foot bellows to intensify the heat, and even in these furnaces the heat was not sufficient to reduce the ore completely to molten metal. Instead, a small spongy ball of iron—called a bloom—was produced in the bottom of the furnace. This was extracted by breaking open the furnace, and then it was hammered into bars of wrought iron, which could be shaped as required by further heating and hammering. Apart from its greater abundance, iron for most purposes provided a harder and stronger material than the earlier metals, although the impossibility of casting it into molds like bronze was an inconvenience. At an early date some smiths devised the cementation process for reheating bars of iron between layers of charcoal to carburize the surface of the iron and thus to produce a coat of steel. Such case-hardened iron could be further heated, hammered, and tempered to make knife and sword blades of high quality. The very best steel in Roman times was Seric steel, brought into the Western world from India, where it was produced in blocks a few inches in diameter by a crucible process, melting the ingredients in an enclosed vessel to achieve purity and consistency in the chemical combination.

Mechanical contrivances

Though slight, the mechanical achievements of the Greco-Roman centuries were not without significance. The world had one of its great mechanical geniuses in Archimedes, who devised remarkable weapons to protect his native Syracuse from Roman invasion and applied his powerful mind to such basic mechanical contrivances as the screw, the pulley, and the lever. Alexandrian engineers, such as Ctesibius and Hero, invented a wealth of ingenious mechanical contrivances including pumps, wind and hydraulic organs, compressed-air engines, and screw-cutting machines. They also devised toys and automata such as the aeolipile, which may be regarded as the first successful steam turbine. Little practical use was found for these inventions, but the Alexandrian school marks an important transition from very simple mechanisms to the more complex devices that properly deserve to be considered “machines.” In a sense it provided a starting point for modern mechanical practice.

The Romans were responsible, through the application and development of available machines, for an important technological transformation: the widespread introduction of rotary motion. This was exemplified in the use of the treadmill for powering cranes and other heavy lifting operations, the introduction of rotary water-raising devices for irrigation works (a scoop wheel powered by a treadmill), and the development of the waterwheel as a prime mover. The st-century-bce Roman engineer Vitruvius gave an account of watermills, and by the end of the Roman era many were in operation.

Agriculture

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History of Technology Timeline

Iron Age technology was applied to agriculture in the form of the iron (or iron-tipped) plowshare, which opened up the possibility of deeper plowing and of cultivating heavier soils than those normally worked in the Greco-Roman period. The construction of plows improved slowly during these centuries, but the moldboard for turning over the earth did not appear until the th century ce, so that the capacity of turning the sod depended more on the wrists of the plowman than on the strength of his draft team; this discouraged tackling heavy ground. The potentialities of the heavy plow were thus not fully exploited in the temperate areas of Europe until after the Roman period. Elsewhere, in the drier climates of North Africa and Spain, the Romans were responsible for extensive irrigation systems, using the Archimedean screw and the noria (an animal- or water-powered scoop wheel) to raise water.

Building

Roman aqueductsA network of Roman aqueducts showing a section undergoing repairs, painting by Michael Zeno Diemer (born ); in the Deutsches Museum, Munich.(more)

Though many buildings of the Greeks survive as splendid monuments to the civilized communities that built them, as technological monuments they are of little significance. The Greeks adopted a form of column and lintel construction that had been used in Egypt for centuries and was derived from experience of timber construction. In no major sense did Greek building constitute a technological innovation. The Romans copied the Greek style for most ceremonial purposes, but in other respects they were important innovators in building technology. They made extensive use of fired brick and tile as well as stone; they developed a strong cement that would set under water; and they explored the architectural possibilities of the arch, the vault, and the dome. They then applied these techniques in amphitheatres, aqueducts, tunnels, bridges, walls, lighthouses, and roads. Taken together, these constructional works may fairly be regarded as the primary technological achievement of the Romans.

Other fields of technology

In manufacturing, transport, and military technology, the achievements of the Greco-Roman period are not remarkable. The major manufacturing crafts—the making of pottery and glass, weaving, leatherworking, fine-metalworking, and so on—followed the lines of previous societies, albeit with important developments in style. Superbly decorated Athenian pottery, for example, was widely dispersed along the trade routes of the Mediterranean, and the Romans made good quality pottery available throughout their empire through the manufacture and trade of the standardized red ware called terra sigillata, which was produced in large quantities at several sites in Italy and Gaul.

Transport

Transport, again, followed earlier precedents, the sailing ship emerging as a seagoing vessel with a carvel-built hull (that is, with planks meeting edge-to-edge rather than overlapping as in clinker-built designs), and a fully developed keel with stempost and sternpost. The Greek sailing ship was equipped with a square or rectangular sail to receive a following wind and one or more banks of oarsmen to propel the ship when the wind was contrary. The Greeks began to develop a specialized fighting ship, provided with a ram in the prow, and the cargo ship, dispensing with oarsmen and relying entirely upon the wind, was also well established by the early years of Classical Greece. The Romans took over both forms, but without significant innovation. They gave much more attention to inland transport than to the sea, and they constructed a remarkable network of carefully aligned and well-laid roads, often paved over long stretches, throughout the provinces of the empire. Along these strategic highways the legions marched rapidly to the site of any crisis at which their presence was required. The roads also served for the development of trade, but their primary function was always military, as a vital means of keeping a vast empire in subjection.

Military technology

Roman military technology was inventive on occasion, as in the great siege catapults, depending on both torsion and tension power. But the standard equipment of the legionnaire was simple and conservative, consisting of an iron helmet and breastplate, with a short sword and an iron-tipped spear. As most of their opponents were also equipped with iron weapons and sometimes with superior devices, such as the Celtic chariots, the Roman military achievements depended more on organization and discipline than on technological superiority.

The Greco-Roman era was distinguished for the scientific activity of some of its greatest philosophers. In keeping with Greek speculative thought, however, this tended to be strongly conceptual so that it was in mathematics and other abstract studies that the main scientific achievements are to be found. Some of these had some practical significance, as in the study of perspective effects in building construction. Aristotle in many ways expressed the inquiring empiricism that has caused scientists to seek an explanation for their physical environment. In at least one field, that of medicine and its related subjects, Greek inquiry assumed a highly practical form, Hippocrates and Galen laying the foundations of modern medical science. But this was exceptional, and the normal Hellenic attitude was to pursue scientific enquiry in the realm of ideas without much thought of the possible technological consequences.