8 How Did They Make and Use Tools?

Technology

The human species has often been defined in terms of our special ability to make tools. And many archaeologists have seen human progress largely in technological terms. The 19th-century Danish scholar C.J. Thomsen divided the human past into "ages" of stone, bronze, and iron. His successors further divided the Stone Age into a Paleolithic period (with chipped or flaked stone tools), and a Neolithic period (with polished stone tools). The later addition of the term Mesolithic (Middle Stone Age) carried with it the implication that the very small flint tools, the "microliths," were somehow characteristic of this particular period of human existence.

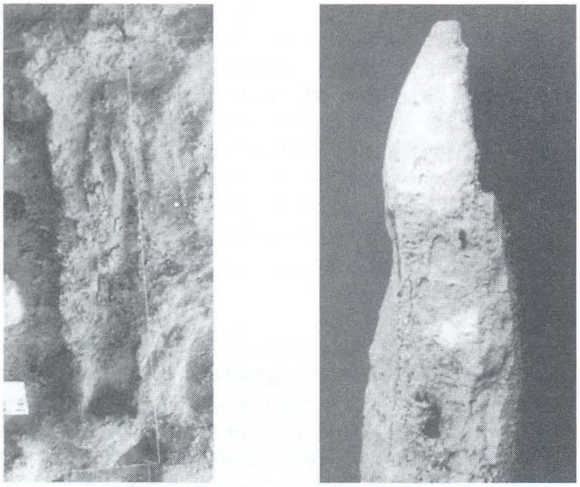
Even if today we do not place so much emphasis on the particular form of artifacts as a reliable chronological indicator, it remains true that these were and are the basic means by which humans act upon the external world. Modern lasers and computers, guns and electrical appliances all have their origins in the simple tools created by our earliest ancestors. It is the physical remains of humanly made artifacts down the ages that form the bulk of the archaeological record. In other chapters we look at how archaeologists can use artifacts to establish typologies (Chapter 4), learn about diet (Chapter 7), discover past patterns of trade and exchange (Chapter 9), and even recreate systems of belief (Chapter 10). Here, however, we address two questions of fundamental importance: how were artifacts made, and what were they used for?

As we shall see, there are several approaches to these two questions – the purely archaeological, the scientific analysis of objects, the ethnographic, and the experimental. Archaeologists should also seek the advice of modern experts in equivalent technologies. Contemporary craftspeople generally exploit the same materials as their forebears, and often use tools that are little changed. An ancient stone wall will be best understood by a stonemason, a brick building by a bricklayer, and a timber one by a carpenter, although in order to understand a medieval timber building, a modern carpenter will certainly need to know something of the period's materials, tools, and methods. For more recently developed technologies, such as those of the last 200 or 300 years, the growing field of ***industrial archaeology*** can also make use of eye-witness accounts by living craftspeople or verbal descriptions handed down from one generation to the next, as well as historical and photographic records.

The student of earlier periods has a narrower range of evidence to choose from. Questions of preservation arise, and indeed of how one decides whether an early "tool" is humanly made in the first place (see box, p. 314).

Survival of the Evidence

When assessing ancient technologies, the archaeologist always needs to bear in mind that the sample preserved may well be biased. During the long Paleolithic period implements of wood and bone must surely have rivaled those of stone in importance – as they do in hunting and gathering societies today – but stone tools dominate the archaeological record. As we saw in Chapter 2, fragile objects may sometimes survive on waterlogged, frozen, or dry sites, but these are exceptions. In view of the poor preservative qualities of many types of artifact, it is worth remembering that even those that have totally decayed can occasionally be detected by the hollows, soil-changes, or marks they have left. Examples include the imprint left in sand by the Sutton Hoo boat in eastern England; the imprint of a textile on a mummy; or, as will be seen below, the space within a mass of corroded metal. The vanished wheel of an Iron Age vehicle in a grave at Wetwang, Yorkshire, in northern England, has been successfully investigated by pumping polystyrene foam into the hollow, revealing that the wheel had 12 spokes. In the royal burials at Ur, Leonard Woolley (p. 34) poured plaster into cavities left by the decayed wooden parts of a lyre. Among the plaster casts of plants at El Cerén, El Salvador (see p. 257), one agave was found to have a strand of braided twine of agave



(Left) A hollow left in the ground by an entirely decayed pointed stick and (right) a plaster cast of one end of this "pseudomorph" from the Middle Paleolithic rockshelter of Abric Romani, Spain.

fiber around it, likewise preserved as a cast. At the Middle Paleolithic rockshelter of Abric Romani in northeast Spain, a "pseudomorph" (i.e. hollow) of a decayed pointed wooden stick, 1 m (3.25 ft) long and dating to almost 50,000 years ago, has been found in sediment; a cast made from the hollow is so detailed that striations on its distal end, revealed by the scanning electron microscope, are clearly similar to tool marks made by experimental woodworking.

Implements are also known from artistic depictions, such as boomerangs and axes stenciled on rockshelter walls by Aborigines in a number of regions of Australia. The former presence of some tools can also be detected by their effects – for example, a sword-cut on a skull, or a pick-mark on a quarry wall.

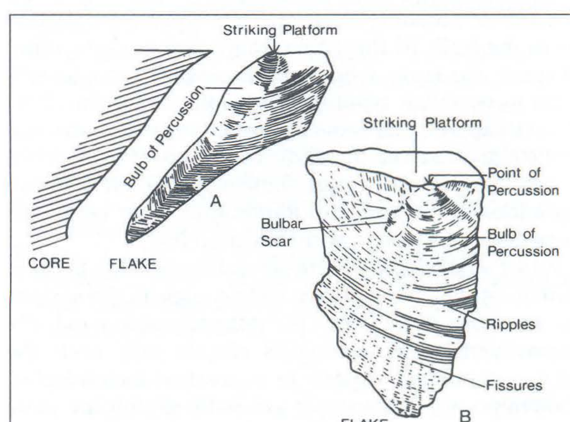
Are They Artifacts at All?

The archaeologist, when studying an object, must first decide whether it was made or used by people in the past. For most periods the answer will be obvious (although one has to beware of fakes and forgeries), but for the Paleolithic, and especially the Lower Paleolithic, judgment can be less straightforward. For many years a vehement debate raged concerning the problem of "eoliths" – pieces of stone found at the beginning of this century in Lower Pleistocene contexts in eastern England and elsewhere and believed by some scholars to have been shaped by early humans, but which other scholars thought were products of nature.

This controversy led to early attempts to establish criteria by which human agency could be recognized, such as the characteristic bulges or "bulbs of percussion" found on pieces of flint purposely struck off (see diagram). Natural fractures caused by factors such as heat, frost, or a fall produce instead irregular scars and no bulb. On this basis the eoliths were pronounced to be of natural origin.

Where the very earliest tools are concerned, however – on which one would expect the traces of human

Depictions of tools and weapons are common on rockshelter walls in Australia. This photograph shows the stencil of a V-shaped "killer" boomerang from the Central Queensland Sandstone Belt. Grahame Walsh and his colleagues estimate that there are 10,000 rock art sites in this area alone.



Features of a purposely made stone flake. Two views (A, B) of a flake struck from the edge of a core show the characteristic striking platform and, immediately beneath, the bulb of percussion and ripples produced by the shock waves after the blow has been struck.

work to be minimal – the question is less easy to resolve, since the crudest human working may be indistinguishable from the damage caused by nature. Here the examination of the context of a particular find may help. It is possible that the stone objects were discovered in association with fossil human remains and animal bones that can be studied for signs of human cutmarks made by stone tools, as described in Chapter 7.

It had traditionally been thought that tool-making separated humans from apes, but the past 30 years of field research have revealed that wild chimpanzees make and use tools of wood and stone; in fact American primatologist William McGrew believes that "some artifacts would be unattributable to [human or chimpanzee] species if they lost their museum labels." In particular, chimpanzees use hammers and anvils to crack nuts. This adds an extra uncertainty to the identification of crude humanly made tools, but also offers archaeologists the chance to "observe" some of the possible tool-making, -using, and -discarding behaviors of early hominids.

A complex case is that of the Calico Hills site, California, where thousands of pieces of fractured stone were found in the 1960s and 1970s in geological deposits dating to around 200,000 years ago. The discoverers claim that many of the stones are tools on the basis of their bulbs of percussion, regular shape, and comparison with tools knapped experimentally from local raw materials. If correct, this would suggest human occupation of the New World at least 160,000 years earlier than is indicated by other sites. It is this extraordinarily early date, itself controversial, and lack of supporting evidence from other sites, as well as the crude nature of the "artifacts," that leads most archaeologists to reject the Calico finds as genuine tools.

A similar debate surrounds artifacts from the rockshelter at Pedra Furada, Brazil (see box overleaf). And yet another example of this controversy is represented by a possible quartzite cobble tool discovered on the Potwar plateau of Pakistan. The date of its conglomerate matrix, 1.9 million years ago, suggests that the widely accepted date of 1.6 million years for the colonization of Eurasia by *Homo erectus* from Africa may need revision.

Interpreting the Evidence: the Use of Ethnographic Analogy

If used with care, evidence from ethnography and ethnoarchaeology can shed light on both general and specific questions concerning technology. At the general level, ethnography and common sense together suggest that people tend to use whatever materials are easily and abundantly available for everyday, mundane tasks, but will invest time and effort into making implements they will use repeatedly (though perhaps rarely) and carry around with them. The abundance of a type of tool in the archaeological record is therefore not necessarily a guide to its intrinsic importance in the culture; the tool most frequently found may well have been quickly made, and discarded immediately after use, while the rarer implement was kept and reused ("curated") several times, before eventually being thrown away.

At the specific level of perhaps identifying the precise function of a particular artifact, ethnography can often prove helpful. For example, large winged pendants of polished stone were found in sites of the Tairona Indians of northern Colombia, dating to the 16th century AD. Archaeologists could only assume that these were purely decorative, and had been hung on the chest. However, it was subsequently learnt that the modern Kogi Indians of the area, direct descendants of the Tairona, still use such objects in pairs, suspended from the elbows, as rattles or tinklers during dances!

There are innumerable examples of this sort. The important point is that the identification of tool forms by ethnographic analogy should be limited to cases where there is demonstrable continuity between archaeological culture and modern society, or at least to cultures with a similar subsistence level and roughly the same ecological background.

In recent years, the archaeological and ethnographic aspects of technological studies have been complemented by the ever increasing interest in bringing archaeology to life through experiment. As we shall see, experiments have contributed a great deal to our understanding of how artifacts were made and what they were used for.

For the purposes of the remainder of this chapter, it is convenient to draw a distinction between two classes of raw material used in creating objects – between those that are largely unaltered, such as flint, and those that are synthetic, the product of human activities, such as pottery or metal. Of course even supposedly unaltered materials have often been treated by heat or by chemical reactions in order to assist the manufacturing process. But synthetic materials have undergone an actual change in state, usually through heat treatment. The human use of fire – pyrotechnology – is a crucial factor here. We are becoming increasingly aware of just how precise human control of fire was at an early date.

ARTIFACTS OR "GEOFACTS" AT PEDRA FURADA?

Debate still rages over the dating of the huge sandstone rockshelter of Pedra Furada in northeast Brazil, excavated by Franco-Brazilian archaeologist Niède Guidon from 1978 to 1984, and Italian archaeologist Fabio Parenti from 1984 to 1988. The original goal of the work was to date the rock paintings on the shelter wall, which were confidently assumed to be of Holocene age (i.e. less than 10,000 years old). When radiocarbon dates of Pleistocene age, extending back more than 30,000 years, started to emerge from the stratigraphy, the site and its excavators were thrust into the forefront of the debate about human origins in the Americas (see box, p. 456). One side (primarily North American) insisted that there was no human occupation in the New World before 12,000 or at best 15,000 years ago; the other side accepted far earlier dates from a number of sites in South America and elsewhere. No site had yet met all criteria necessary to convince skeptics that humans had been in the New World 30,000 years ago, so Parenti set out to tackle the problem.

Parenti's task was made particularly difficult because the sediments of the sandstone shelters of this region of Brazil have destroyed all organic materials (other than charcoal fragments) in pre-Holocene levels. In addition, the Pleistocene levels of Pedra Furada contain tools made only of the quartz and quartzite pebbles from a conglomerate layer above the sandstone cliff, and pebble tools are notoriously difficult to differentiate from naturally broken stones.

Parenti's primary aim, therefore, after erosional, geomorphological, and sedimentary study of the site and its surroundings, was to distinguish between human and natural agencies in terms of the site's contents in general, and of its lithic objects in particular. The stratigraphy comprised mostly sand as well as sandstone plaques that had fallen from the walls, with occasional rubble layers. It was a natural rubble "wall" in front of the shelter that had preserved the sediments within. The site has a series of 54 radiocarbon dates ranging from 5000 to 50,000 years BP.

Where the pebbles are concerned, Parenti conducted a study of 3500 stones fallen from the clifftop, and found that when they break – which is rare – the natural flaking never affects more than one side, never removes more than three flakes, and never produces "retouch" or "micro-retouch." These observations became his benchmark for recognizing human artifacts at the site. Of some 6000 pieces definitely considered to be tools, 900 came from the Pleistocene layers (quartz and quartzite continued to be worked and used in the same way in the Holocene, but easily identifiable chalcedony pieces account for the high number of definite tools in that period). Thousands more pebbles are ambiguous, and could be either natural or humanly made.

Of the few specialists who have managed to visit this remote site, some remain highly skeptical of all the excavators' claims, including the criteria employed to identify the artifacts, while others are equally certain that the pebbles are definitely tools and that the site was occupied long before the Holocene.

Pebble "tool" *from Pedra Furada. Debate continues as to whether these quartzite "artifacts" are natural or humanly-made.*

The rockshelter *at Pedra Furada (left) where "tools" (top right) were excavated and controversial evidence for occupation dating back 30,000 years has been found.*

UNALTERED MATERIALS: STONE

From the first recognizable tools, dating back about 2.5 million years, up to the adoption of pottery-making, dated to 14,000 BC in Japan, the archaeological record is dominated by stone. How were stone artifacts, from the smallest microlith to the greatest megalith, extracted, transported, manufactured, and used?

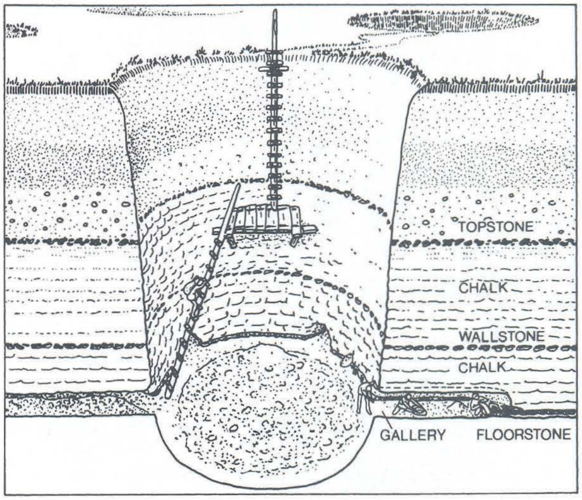
Extraction: Mines and Quarries

Much of the stone for early tools was probably picked up from streambeds or other parts of the landscape; but the sources most visible archaeologically are the mines and quarries.

The best-known ***mines*** are the Neolithic and later flint mines in various parts of northern Europe, such as at Spiennes in Belgium, Grimes Graves in England, and Krzemionki in Poland. The basic technology remained fundamentally the same for the later extraction of other materials, such as salt in the Iron Age mines at Hallstatt, Austria, copper at mines such as Rudna Glava and Ai Bunar in former Yugoslavia, and Great Orme in Wales, and silver and gold from mines of later periods.

Excavation has revealed a mixture of open-cast and shaft mining, depending on the terrain and the position of the desirable seams (a high degree of expertise is usually clear from the ignoring of mediocre seams and a concentration on the best material). For example, at Rijckholt in the Netherlands, archaeologists dug an exploratory tunnel for 150 m (490 ft), following the layer of chalk that Neolithic people of the 4th millennium BC had found to be especially rich in flint nodules. No fewer than 66 mine-shafts were encountered, 10–16 m (33–52 ft) deep, each with radiating galleries that had been backfilled with waste chalk. If the archaeologists' tunnel hit a representative sample of shafts, then the Rijckholt area must contain 5000 of them, which could have yielded enough flint for a staggering 153 million axeheads.

There were a variety of clues to the mining techniques at Rijckholt. Impressions in the walls of an excavated shaft indicated that cave-ins were prevented by a retaining wall of plaited branches. Deep grooves in the chalk at the points where the shafts end and the galleries begin imply that ropes were used to raise nodules to the surface. As for the tools used, over 15,000 blunted or broken axeheads were found, suggesting a figure of 2.5 million for the whole mine; in other words, less than 2 percent of the output was expended in extraction. Each shaft had about 350 axeheads – some next to the hollows in the waste chalk left by their vanished wooden handles – and it has been estimated that five would have been worn out in removing a single cubic meter of chalk. They were sharpened on the spot, as is shown by the hard hammerstones found with them (one for every 10 or 20 axeheads) and the abundant flakes of flint.

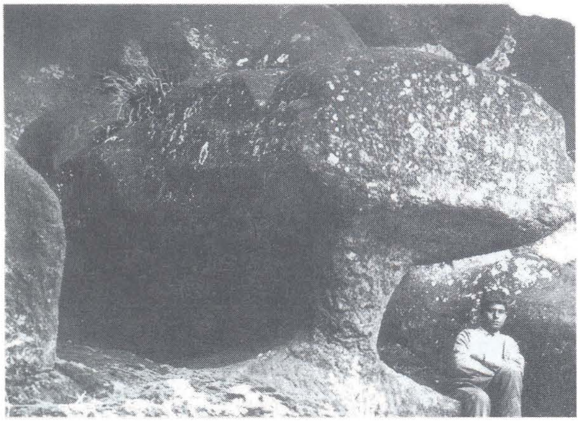


Neolithic flint mine at Grimes Graves, eastern England. Shafts some 15 m (50 ft) deep were sunk to reach the best-quality flint in the floorstone layer. Galleries, once exhausted, were back-filled with rubble from new galleries. Rough estimates suggest that the site could have produced 28 million flint axes.

Few antler picks were found at Rijckholt as the chalk there is particularly hard, but they are known from other such mines. Experiments have shown how remarkably effective antler can be against hard rock. Traces of burning in other mines also indicate that rock faces were sometimes initially broken up by heating with a small fire.

Finally, at copper mines in the Mitterberg area of the Austrian Alps some wooden tools have survived – a hammer and wedges, a shovel and torch, a wooden sled for hauling loads, and even a notched tree-trunk ladder. Such finds indicate the range of technological evidence missing from most sites and which we have to rediscover through analysis of clues such as those at Rijckholt.

Where ***quarries*** are concerned, the archaeologist is often aided in making technological reconstructions by unfinished objects or abandoned stones. The most impressive examples are the statue-quarry on the slopes of the volcano Rano Raraku, Easter Island, and



Stone quarry on Easter Island: one of the giant statues lies flat on its back, unfinished but at an advanced stage of manufacture – yielding clues as to how it was made.

the obelisk quarry at Aswan, Egypt. The Easter Island quarry contains scores of unfinished statues at various stages of manufacture, from a shape drawn on to a rock face to a completed figure attached to the rock only at the base. Discarded hammerstones by the thousand litter the area. Experiments have suggested that six carvers with such stone picks could have shaped a 5-m (16-ft) statue in about a year.

The granite obelisk at Aswan, had it been finished, would have been 42 m (138 ft) high and weighed an immense 1168 tons. The tools used in its initial shaping were heavy balls of dolerite, and experiments indicate that pounding the granite with them for one hour would reduce the level of the obelisk by 5 mm (0.2 in) over each person's work area. At that rate, the monument could have been shaped and undercut in 15 months by 400 workers, giving us some objective indication of the magnitude of Egyptian work of this kind. The pounding marks still visible in the Aswan quarries are very similar to marks on rocks at sites such as Rumiqolqa, Peru. This quarry, the most complete Inca quarry known, has 250 shaped blocks lying abandoned in an enormous pit 100 m (328 ft) long; the blocks had been pounded into shape with hardstone hammers which still bear the traces of the work.

Archaeology, combined with experiments, can thus discover a great deal about stone extraction. The next stage is to ascertain how the material was moved to the place where it was used, erected, or fitted together.

How was Stone Transported?

In certain cases, simple archaeological observation can assist inquiry. At the Inca quarry of Kachiqhata, near the unfinished site of Ollantaytambo, the Swiss architectural historian Jean-Pierre Protzen's investigations have revealed that slides and ramps were built to enable the workers to move the red granite blocks 1000 m (1094 yd) down the mountain. But discovering the route is one thing – the technique is another. For this, wear patterns need to be studied. At Ollantaytambo itself, Protzen noted drag marks (polishing, and longitudinal striations) on some blocks; and since the marks are found only on the broadest face, it is clear that the blocks were dragged broad-face down.

It is not yet known how the dragging was accomplished, and commentaries by the 16th-century Spanish Conquistadors are of little help on this point. Perhaps the most challenging problem is how the ropes and men could have been arranged. At Ollantaytambo, for example, one block of 140 tons would have required 2400 men to move it, yet the ramp up which it was moved was only 8 m (26 ft) wide. Only experimentation will indicate the most feasible method employed.

The Egyptians faced similar and often greater problems in the transportation of huge blocks. Here, we have some information from an ancient representation showing a 7-m (23-ft) high alabaster statue of Prince Djehutihetep being moved (see illus. p. 417); it must have weighed 60 tons. The statue is tied to a wooden sledge, and 90 men are pulling on ropes. This number was probably insufficient, and must be attributed to artistic licence; but at least depictions of this type serve to counter suggestions that huge statues and blocks could only be moved with the help of visiting astronauts. Calculations by engineers and actual experiments are probably the best way in which we can hope scientifically to solve the enigma of how great stone blocks – like the 300-ton Grand Menhir Brisé in Brittany or the trilithons at Stonehenge, England – were transported and erected (see box overleaf), although debate still rages as to whether the Stonehenge bluestones were brought from Wales by its builders, or were found more locally because they had been transported there by glaciers.

One experiment, in 1955, tackled the great Olmec basalt columns or stelae at La Venta, Mexico, of the 1st millennium BC. Real-life trials proved a 2-ton column was the maximum load that could be lifted by 35 men, using rope slings, and poles on their shoulders. Since the largest La Venta stela weighs 50 tons, it must have required 500 men, at 100 kg (220 lb) per man. But 500 people could not all have got near enough to lift the stela, so it was deduced that the stone must have been dragged instead.

Moving the stones: an experiment at Bougon, western France, in 1979. Three large wooden levers – each maneuvered by a team of 20 people – were used to erect a Neolithic block weighing 32 tons. Supporting wedges held the block as it rose.

How were Stones Worked and Fitted?

Here again, archaeology and experiment combine to provide valuable insights into construction techniques. For example, Inca stonework has always been considered a marvel, and the accuracy with which blocks of irregular shape were joined together once seemed almost fantastic. Jean-Pierre Protzen's work has revealed many of the techniques involved, which, though mundane, by no means detract from the Inca accomplishment. His experiments determined the most effective way to "bounce" hammerstones on the blocks to dress them (see illus. p. 319), and found that one face could easily be shaped in 20 minutes. The bedding joint for each course of stones was cut into the upper face of the course already in place; then the new block was placed on the lower, the required edge outlined, and that shape pounded out of it with a hammerstone.

Protzen found that a fit could be obtained in 90 minutes, especially as practice gave one a keen eye for matching surfaces. His experiments are supported by 16th-century accounts which state that many fits were tried until the stones were correctly adjusted. The Inca blocks also bear traces of the process – their surfaces are covered in scars from the hammerstones, while the finer scars on the edges indicate the use of smaller hammers. In addition, many blocks still have small protrusions which were clearly used when handling them. Similar protruding knobs can also be seen on certain Greek buildings, such as the unfinished temple at Segesta, Sicily.

Until recently we had little knowledge of exactly how Greek architects achieved such precision in both the design and execution of their buildings, since no written accounts or plans have survived. But the German archaeologist Lothar Haselberger has now found "blueprints" in the form of detailed drawings on the walls of the 4th-century BC temple of Apollo at Didyma, Turkey. Thin lines up to 20 m (65 ft) long, forming circles, polygons, and angles, had been etched into the marble with a fine metal gouge. Some drawings were full size while others were scaled down; different parts of the building could be recognized, and, since the walls bearing the drawings should logically have been built before the walls depicted in the drawings, the sequence of construction could thus be determined.

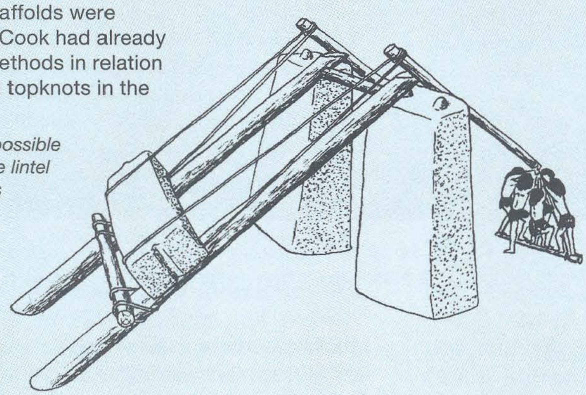
RAISING LARGE STONES

For centuries, scholars have puzzled over the problem of how Stone Age people managed to raise tremendously heavy stones onto the top of high uprights: most famously at Stonehenge, where horizontal lintel stones are accurately fitted on to the top of pairs of uprights to form "trilithons," but also on Easter Island, where many of the statues had *pukao* or topknots (cylinders of red volcanic stone, weighing 8 tons or more) placed on their heads.

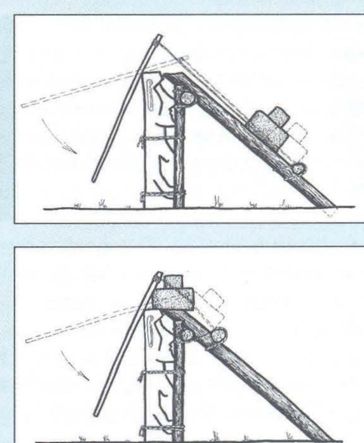
It has traditionally been assumed that enormous ramps of earth or imposing timber scaffolds were required – Captain Cook had already suggested these methods in relation to the Easter Island topknots in the late 18th century. Others have suggested – for both Stonehenge and Easter Island – that the lintels/topknots were lashed to the uprights or statues and the whole unit raised together. However, this is not only very difficult but archaeologically unlikely – the Easter Island topknots were clearly a later addition to the statues. The few that have been placed on to restored statues in modern times have had to be raised by cranes.

Czech engineer Pavel Pavel has found that the feat is actually quite straightforward, requiring just a few people, ropes, and some lengths of timber. He began by working with a clay model of Stonehenge, and, when the method appeared to work, he built a full-size concrete replica of two upright stones and a lintel. Two oak beams were leaned up against the top of the uprights, and two other beams were installed as levers at the other side. The lintel – attached by ropes to the levers – was gradually raised up the sloping beams, which were lubricated with fat. The whole operation was achieved by 10 people in only 3 days.

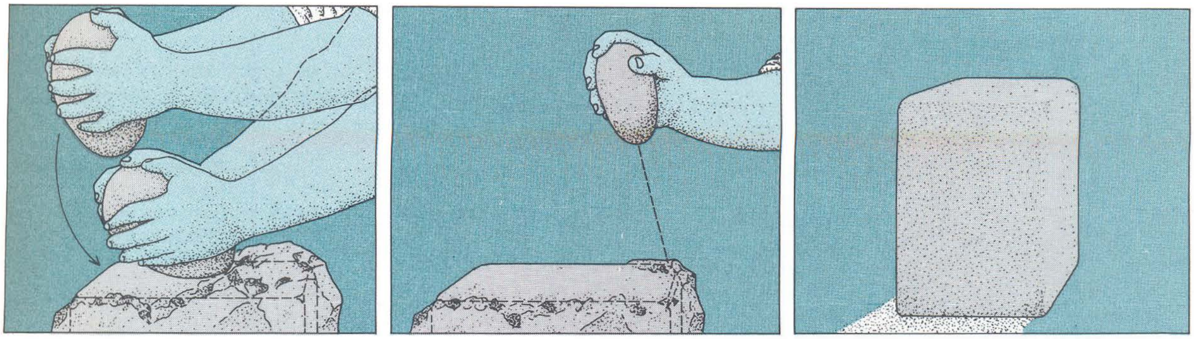
Pavel has subsequently carried out a similar experiment with a replica Easter Island statue and *pukao*, again finding that the method worked perfectly and with little effort. As with all such experiments, one cannot prove that the Stone Age people used this technique, but the probability is high that something of the kind was employed. The work shows that modern people, so accustomed to using machinery, tend to overestimate the difficulties involved in stone monuments, and underestimate what can be achieved with a little ingenuity, a few people, and simple technology.



Reconstruction *of a possible method used to lift the lintel stones of the trilithons at Stonehenge.*



Two stages *in the possible method of raising the topknot on the Easter Island statues. Modern experiments have shown that this method works perfectly.*



Inca stonework. (Below) The famous 12-angled stone in Cuzco, Peru, part of a wall of accurately fitted blocks built by the Incas. (Above) Diagrams illustrating Jean-Pierre Protzen's experiments to discover how Inca stonemasons may have dressed the blocks. Initially (left) Protzen pounded one face of the stone with a 4-kg (9-lb) hammer which he twisted at the last minute to deliver a glancing blow. Then (center) he used a smaller 560-g (1.2-lb) hammer to prepare the edges of the next face. Having repeated the process for each face, he finally produced a finished block (right) with slightly convex corners, similar to the corners on actual Inca stonework.

Other Greek temples have since been found to contain similar plans, but the Didyma drawings are the most detailed, and survived because the walls never received their customary final polish which would have obliterated the engravings. More recently, a full-size blueprint for part of the façade of Rome's Pantheon of AD 120 has been identified, chiseled into the pavement in front of the Mausoleum of Augustus. In Chapter 10 we consider the importance of plans in terms of the development of human intellectual skills.

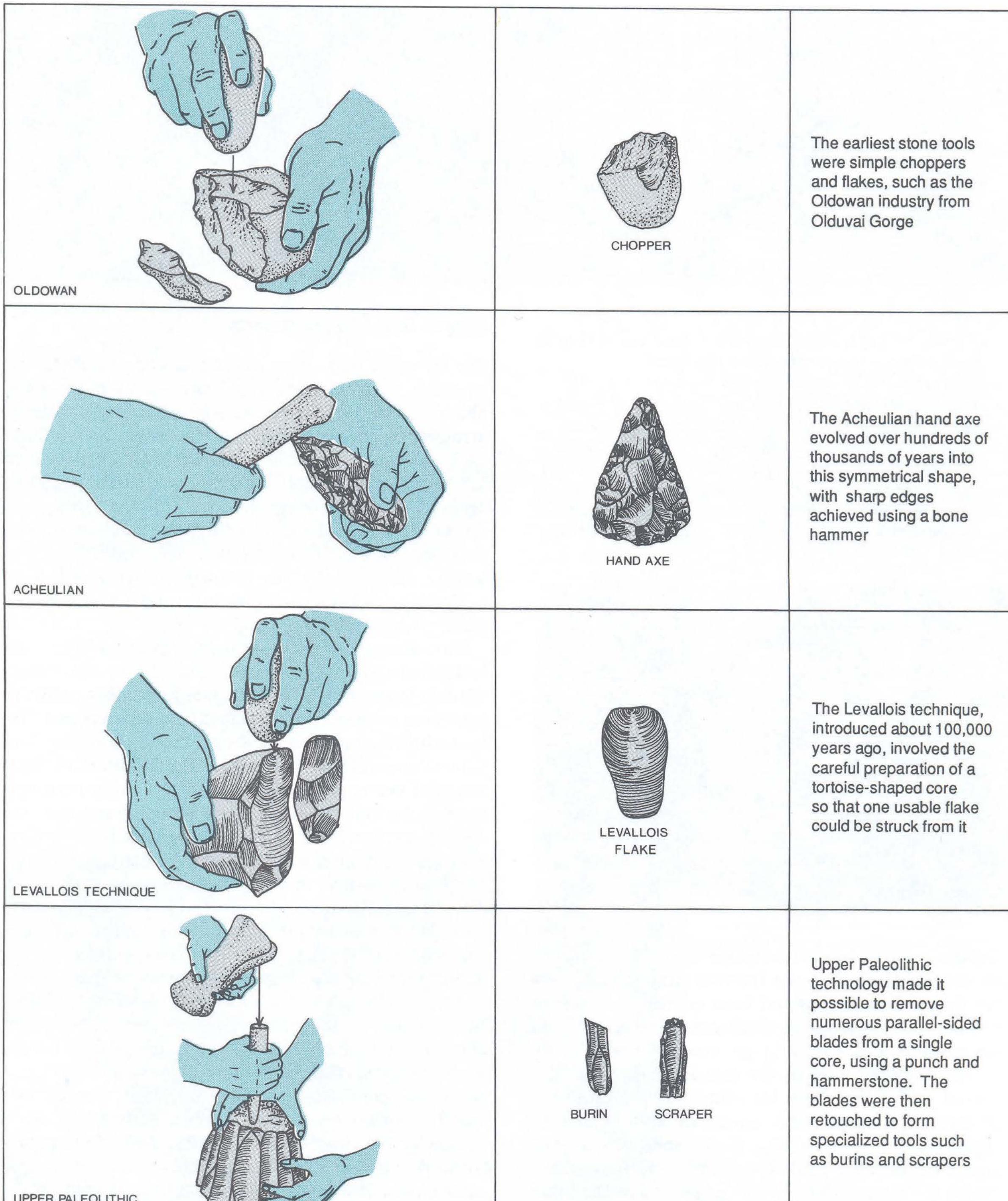
So far we have examined the larger end of the lithic spectrum. But how were the smaller stone objects made? And what was their purpose?

Stone Tool Manufacture

For the most part, stone tools are made by removing material from a pebble or "core" until the desired shape of the core has been attained. The first flakes struck off (primary flakes) bear traces of the outer surface (cortex). Trimming flakes are then struck off to achieve the final shape, and certain edges may then be "retouched" by further removal of tiny secondary flakes. Although the core is the main implement thus produced, the flakes themselves may well be used as knives, scrapers etc. The toolmaker's work will have varied in accordance with the type and amount of raw material available.

The history of stone tool technology shows a sporadically increasing degree of refinement. The first recognizable tools are simple choppers and flakes made by knocking pieces off pebbles to obtain sharp edges. The best-known examples are the so-called Oldowan tools from Olduvai Gorge, Tanzania. After hundreds of thousands of years, people progressed to flaking both surfaces of the tool, eventually producing the symmetrical Acheulian hand-axe shape, with its finely worked sharp edges. The next improvement, dating to around 100,000 years ago, came with the introduction of the "Levallois technique" – named after a site in a Paris suburb where it was first identified – where the core was knapped in such a way that large flakes of predetermined size and shape could be removed.

Around 35,000 years ago, with the Upper Paleolithic period, blade technology became dominant in some parts of the world. Long, parallel-sided blades were systematically removed with a punch and hammerstone from a cylindrical core. This was a great advance, not only because it produced large numbers of blanks that could be further trimmed and retouched into a wide range of specialized tools (scrapers, burins, borers), but also because it was far less wasteful of the raw material, obtaining a much greater total length of working edges than ever before from a given amount



The evolution of stone tools, from the earliest, Oldowan technology to the refined methods of the Upper Paleolithic.

of stone. The stone itself was normally a homogeneous easily worked type such as chert or obsidian. Loren Eiseley has worked out a helpful summary of this increasing efficiency, estimated assuming the use of 500 g (1 lb 1 oz) of high-quality chert:

Technology	**Length of Cutting Edge Produced**
OLDOWAN	5 cm
ACHEULIAN	20 cm
MOUSTERIAN (Middle Paleolithic)	100 cm
GRAVETTIAN (Upper Paleolithic)	300–1200 cm

This trend toward greater economy reached its peak in the Mesolithic (Middle Stone Age), around 10,000 years ago, with the rise to dominance of microliths, tiny stone tools many of which were probably used as barbs on composite implements.

The archaeologist has to reconstruct the sequence of manufacturing steps – the ***chaîne opératoire*** (see p. 388) – a task made easier if the knapping was done in one place and all the waste material (debitage) is still present. The discovery of a network of manufacturing sites also aids analysis. In Japan, the Taku site cluster of over 40 sites in Saga Prefecture, dating to between 15,000 and 10,000 years ago, is located at a stone source and yielded over 100,000 tools, with each site specializing in a different stage of manufacture, from raw material procurement to production of finished artifacts. More commonly, however, the archaeologist will find an industrial site with a full range of waste material and broken tools, but few finished tools since these were mostly removed. Finished tools often turn up in sites far from the stone source. The types of tools found at a site can also provide clues to its function: a hunting kit with projectile points might be expected in a temporary camp, while a wide range of tools would be present in a base camp or a permanent settlement.

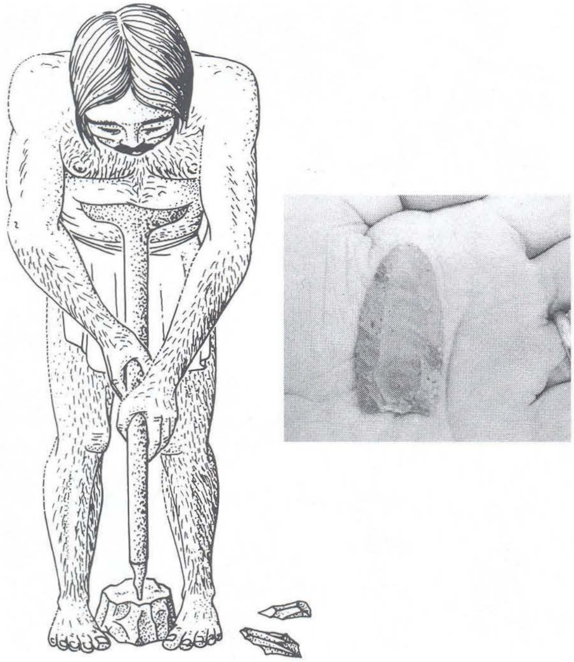
Some techniques of manufacture can be inferred from traces left on the tools – e.g. traces of what seems to be a mastic made of heated bitumen found on several stone tools from Umm el-Tlel in Syria suggest that hafting dates back at least to the Middle Paleolithic. Many techniques can still be observed among the few living peoples, such as some Australian Aborigines or highland Maya, who continue to make stone tools. Much ethnoarchaeological work has been done in Australia and Mesoamerica in recent years, most notably by Richard Gould and Brian Hayden. Others have investigated how New Guinea highlanders manufacture stone axes. Artistic depictions can also be of some help, as in the paintings in the tomb of the 12th-dynasty Egyptian pharaoh Ameny at Beni Hassan, which show the mass production of flint knives under the supervision of foremen.

One of the acknowledged masters of stone tool replication: the French Paleolithic specialist, François Bordes. He is seen here in 1975, knapping a piece of stone in order to assess the processes involved and the time and effort expended.

In most other cases, there are two principal approaches to assessing what decisions the knapper made: replication and refitting.

Stone Tool Replication. This is a type of experimental archaeology that involves making exact copies of different types of stone tool – using only the technology available to the original makers – in order to assess the processes entailed, and the amount of time and effort required. In the past only a handful of experimenters, notably François Bordes in the Old World and Donald Crabtree in the New, reached a high level of expertise, since many years of patient practice are required. Today, however, quite a few archaeologists have become proficient at tool replication, much to the benefit of our knowledge of ancient stone-knapping.

American archaeologist Nicholas Toth, for example, has made and used the entire range of early stone tools, as found at sites such as Koobi Fora, Kenya, and dating to about 1.5 to 2 million years ago – hammerstones, choppers, scrapers, and flakes. His work provides



How were Paleo-Indian Folsom points made? Experiments by Donald Crabtree showed that the flakes were pressed from the core using a T-shaped crutch (left). Flintknappers have produced almost perfect replica points (right).

evidence to suggest that simple flakes may have been the primary tools, while the more impressive cores were simply an incidental by-product of flake manufacture. Previously, scholars tended to see the flakes as waste products, and the cores as the intentional end-product.

One specific problem that Donald Crabtree was able to solve through trial and error was how the Paleo-Indians of North America had made their fluted stone tools known as Folsom points, dating to some 11,000–10,000 years ago. In particular, how had they removed the "flute" or channel flake? This had remained a mystery and experiments with a variety of techniques met with disappointing results, until the decisive clue was found in a 17th-century text by a Spanish priest who had seen Aztec Indians make long knife-blades from obsidian. The method, as experiments proved, involves pressing the flake out, downward, by means of a T-shaped crutch placed against the chest; the crutch's tip is forced down against a precise point on the core which is clamped firm.

Another Paleo-Indian specialist, American archaeologist George Frison, wanted to know how the slightly earlier Clovis projectile points were used. He tested replicas, 5–10 cm (2–4 in) long and hafted onto 2-m (6.5-ft) wooden shafts with pitch and sinew, to show that, when thrown from 20 m (65 ft), they penetrated deeply into the back and ribcage of (already mortally wounded) elephants in Africa. Frison discovered that the points could be used up to a dozen times with little or no damage, unless they hit a rib.

Archaeologists can also use replication and experiment to discover whether certain flint tools had been deliberately heated during manufacture, and if so, why. For example, in Florida many projectile points and much chipping debris have a pinkish color and a lustrous surface which suggests thermal alteration. Work by Barbara Purdy and H.K. Brooks has shown that when Florida cherts are slowly heated a color change occurs at 240°C (464°F), while after heating to 350–400°C (662–752°F) flaking leaves a lustrous appearance. Purdy and Brooks investigated the differences between unheated and heated chert. Petrographic thin-sections failed to detect any differences in structure, but in the scanning electron microscope it became clear that heated chert had a far smoother appearance. Furthermore, a study of rock mechanics showed that after heating the chert had an increase in compressive strength of 25–40 percent, but a decrease of 45 percent in the force needed to break it.

Confirmation – and more objective data than a flint's appearance – can be obtained from an entirely different method, electron spin resonance (ESR) spectroscopy, which can identify defects or substitutions within the structure of crystals – in this case within the silica. Heated material has a characteristic ESR signal which is absent from unheated flint, and which remains stable indefinitely. Tests with this method have proved that heat treatment was already present in the French Upper Paleolithic Solutrean culture, about 19,000 years ago. The heating was clearly performed after initial shaping but before final trimming. Experiments by Crabtree on chert indicate that one can obtain larger flakes by pressure flaking after heating. Thermoluminescence (Chapter 4) can also be used to detect heat alteration – and, in some cases, even estimate the temperature – as the amount of TL in a sample relates to the time since firing. A tool not subjected to heat normally yields a high TL reading, while a heated specimen has a far lower reading due to the previous release of trapped electrons.

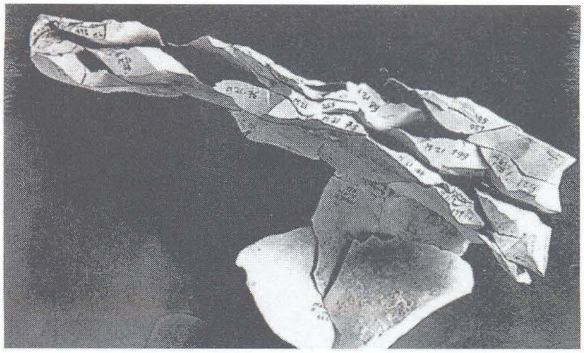
Replication cannot usually prove conclusively which techniques were used in the past, but it does narrow the possibilities and often points to the most likely method, as in the Folsom example above. *Refitting*, on the other hand, involves working with the original tools and demonstrates clearly the precise chain of actions of the knapper.

Refitting of Stone Tools. This type of work, which can be traced back to F.C.J. Spurrell at the Paleolithic site of Crayford, England, in 1880, has really come into its own in the last couple of decades thanks largely to the efforts of André Leroi-Gourhan at the Magdalenian (late Upper Paleolithic) camp of Pincevent, near Paris, and that of his pupils at similar sites. Refitting, or conjoining as it is sometimes called, entails attempting to put tools and flakes back together again, like a 3-D jigsaw puzzle. The work is tedious and time-consuming, but can produce spectacular results. One refitted stone designated N103 from the Magdalenian site of Etiolles includes 124 pieces, some of which are blades over 30 cm (12 in) long.

Why exactly do archaeologists devote so many hours of hard work to refitting exercises? Very broadly because refitting allows us to follow the stages of the knapper's craft and – where pieces from one core have been found in different areas – even the knapper's (or the core's) movements around the site. Of course, displacement of flakes may have nothing to do with the changing location of the craftsperson: a burin spall, for example, can jump 7 m (23 ft) when struck off. And it should not be assumed automatically that each core was processed in one episode of work: we know from ethnography that a core can be reused after a short or long period of absence.

It is also now known from conjoined pieces that considerable vertical movement can occur through different layers of a site, even where there are no visible traces of disturbance. However, if these factors are allowed for, refitting provides a dynamic perspective on the spatial distribution of tools, and produces a vivid picture of actual movement and activity in an ancient site. Where these observations can be supplemented by information on the functions of the tools, the site really comes to life (see box overleaf, on the site of Meer).

But how can we discover the function of a stone tool? Ethnographic observation often gives valuable clues, as we have already seen, as do residues (p. 302); and experimentation can determine which uses are feasible or most probable. However, a single tool can be used for many different purposes – an Acheulian hand-axe could be used for hacking wood from a tree, for butchering, smashing, scraping, and cutting – and conversely the same task can be done by many different tools. The only direct *proof* of function is to study the minute traces, or microwear patterns, that remain on the original tools.



Stone flakes from the Upper Paleolithic site of Marsangy, France, refitted to show the original core from which they were struck. Such work allows the archaeologist to build up a picture of the different stages of the knapper's craft.

Identifying the Function of Stone Tools: Microwear Studies

Like refitting, microwear studies can be traced back into the 19th century; but the real breakthrough came with the pioneering work, first published in 1957, by Sergei Semenov of the Soviet Union, who had experimented for decades with the microwear on ancient tools. Employing a binocular microscope, he found that even tools of the hardest stone retained traces of their use: primarily a variety of polishes and striations. Subsequent work by Ruth Tringham and others showed that Semenov's striations were not as universal as he had claimed, and attention was focused on microflaking (minute edge-chipping caused by use). Then the work entered a new phase with the introduction of the scanning electron microscope, which enabled Lawrence Keeley, now of the University of Chicago, and others to be far more precise about types of microwear and to record them on photomicrographs.

Describing the wear was all very well, but the different types needed to be identified with specific activities; experimental archaeology proved to be the answer. Different sorts of stone tools were copied, and each was used for a specific task. Study of the traces left by each task on different types of stone allowed Keeley to establish a reference collection with which wear on ancient tools could be compared. He found that different kinds of polish are readily distinguishable, and are very durable, since they constitute a real alteration in the tools' microtopography. Six broad categories of tool use were established: on wood, bone, hide, meat, antler, and non-woody plants. Other traces show the movement of the tool – e.g. in piercing, cutting, or scraping.

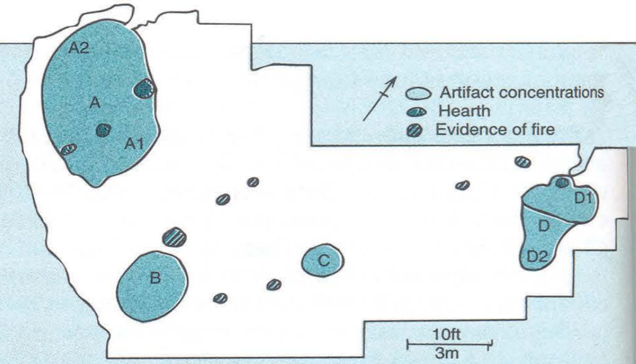
The effectiveness of this method was verified in a blind test, in which Keeley was supplied with 15 replicas that had been used for a series of secret tasks. He was able to identify correctly the working portions of the tool, reconstruct the way in which it was used, and even the type of material worked in almost every case. Turning to Lower Paleolithic artifacts from southern England, Keeley found that tools from Clacton (about 250,000 years old) had been used on meat, wood, hide, and bone, while some from Hoxne had also been used on non-woody plants. Sidescrapers seemed to have been used primarily for hide-working.

In a similar study, Johan Binneman and Janette Deacon tested the assumption that the stone adzes from Boomplaas Cave, South Africa, had been used primarily for woodworking (see Chapter 6 for the importance of charcoal at this site). Replicas of the later Stone Age tools were made and then used to chisel and plane wood. When the resulting use-wear was compared with that on 51 tools from the site, dating back to 14,200 years ago, it was found that all the prehistoric specimens had the same polish, thus confirming the early importance of woodworking here.

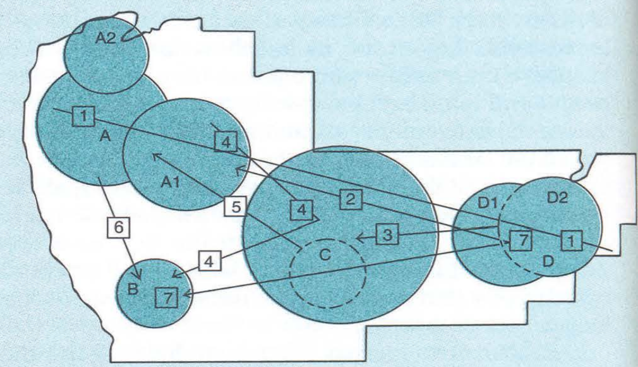
The Japanese scholar Satomi Okazaki has focused on striations, since she feels that study of their density and direction is more objective than an assessment of degree of polish. In experiments she found that using obsidian produces striations, but no polish: striations parallel to the tool-edge are the results of a cutting motion, while perpendicular striations result from a scraping motion.

Establishing the function of a set of tools can produce unexpected results which transform our picture of activity at a site. For example, the Magdalenian site of Verberie, near Paris (12th millennium BC), yielded only one bone tool; yet studies of microwear on the site's flint tools show the great importance of bone-working: an entire area of the site seems to have been devoted to the working of bone and antler. Some traces adhering to stone tools, such as blood or phytoliths, also provide clues about function (Chapter 7).

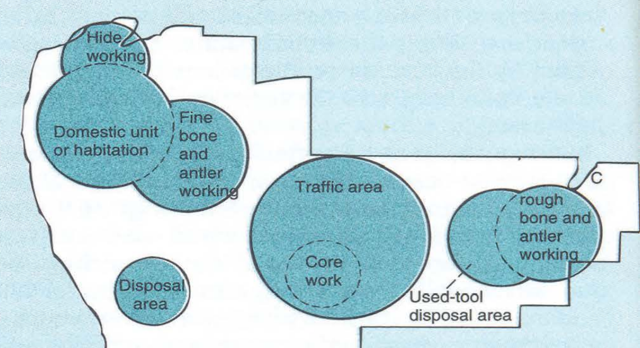
As mentioned above, when microwear studies are combined with refitting, they help to produce a vivid picture of prehistoric life. At another French Magdalenian site, Pincevent, the tools and manufacturing waste generally cluster around the hearths; one particular stone core was found to have had a dozen blades removed from it beside one hearth, and eight of the blades had been retouched. The same core was later moved to a different hearth and work recommenced; some of the flakes struck off here were made into tools such as burins (graving implements), all of which were used to work reindeer antler.



Excavation of the Meer site revealed four concentrations of artifacts – A, B, C, and D; the largest were A and D. Within area A were two "satellite" areas (A, and A_2) and 3 hearths. Area D also had two "satellites," but only one hearth.



***Refitting studies** have demonstrated links among the four Meer II concentration areas as shown in the diagram above. Each of these seven links traces one or more artifacts from one area to another.*



***Microwear analysis** of Meer II artifacts has produced this plan, showing the breakdown and separation of activities at the site.*

REFITTING AND MICROWEAR STUDIES AT THE MEER SITE

The Epipaleolithic (Mesolithic) site of Meer II, Belgium, dates from about 8900 years ago, and was excavated by the Belgian archaeologist Francis Van Noten in 1967–69 and 1975–76. Apart from a few fragments of eroded bone and scraps of charcoal and ocher, the site comprises a scatter of stone tools in a sand dune. There were hammerstones of quartzite and schist, and grinders of sandstone, but 98 percent of the 16,000 stone artifacts were of flint.

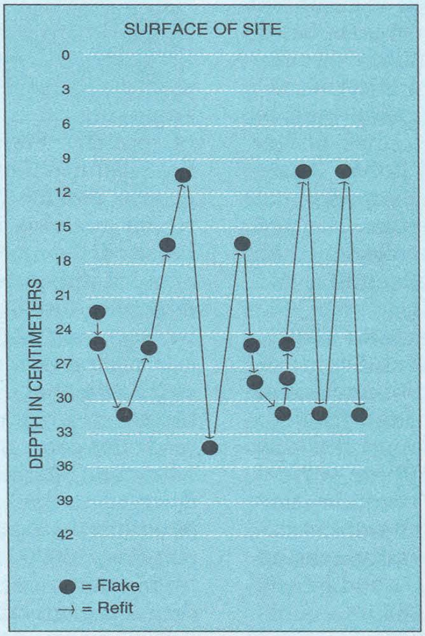
Van Noten plotted the horizontal distribution of the tools, which showed marked variation. Some meter squares had over 500 artifacts, others few or none, and there were four particular concentrations (labeled A to D on the site plan). Vertically, the tools were found scattered through a considerable depth of 45 cm (1ft 6 in). Did this mean that the site had been occupied several times, or had the abandoned tools from a single occupation been displaced vertically by natural processes, such as burrowing animals and plant roots?

In order to answer this question, a refitting project was carried out by Daniel Cahen, who succeeded in reconstituting many of the small flint nodules. He found that 18 percent of the artifacts were interrelated, and that there were definite links among the four areas of concentration. The work suggests strongly that occupation was shortlived and that the vertical displacement of tools is indeed due to natural post-depositional factors.

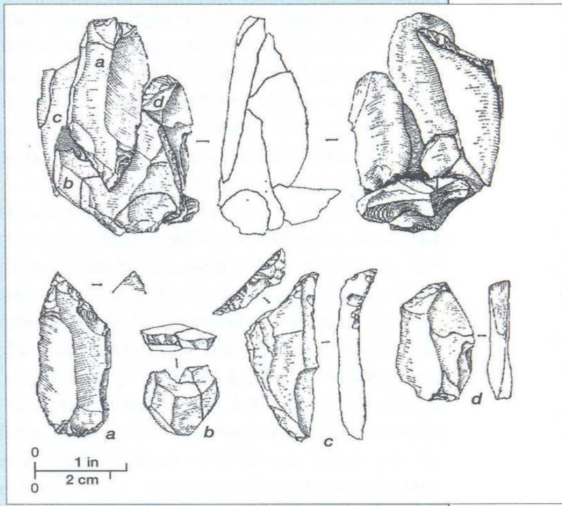
When his results were combined with analysis of microwear traces by Lawrence Keeley, a remarkably detailed picture emerged of some activities at what had, at first, appeared an unpromising site.

For example, out of one group of 15 tools refitted from concentration D, 12 showed microwear. The microwear indicated that one tool had been used to cut meat, while the others had all been used on bone – 8 as borers, 4 as groovers, and 2 as cutters. From this and other similar evidence, it was deduced that concentration D had been an area where flint tools were prepared for rough work on bone and antler. Furthermore, three of the boring tools in concentration D had done their work by being twisted counter-clockwise, unlike the other borers which had been turned clockwise. It is therefore very likely that more than two people worked at concentration D, one of whom was left-handed.

At various stages right-handed knappers carried blanks and finished tools from concentration D to concentration A, where they were used for fine work on bone. Other small areas seem to have been used for hide-working and as a refuse dump.



***Graph showing** how a group of 17 flakes, from varying depths at the site, could be refitted – the arrows indicating refits among flakes struck successively from the same core. This demonstrates that the artifacts, although as much as 24 cm apart in depth, were from the same occupation period at the site. Disturbance of the soil by roots and other natural forces had displaced the flakes vertically through the deposit.*



***Microwear and refitting** studies combined. (Top row) Three views of a refitted block. (Bottom row) Microwear indicated a variety of uses for the flakes: **a**, borer for use on bone; **b**, tool for incising grooves in bone; **c**, another borer for bone; **d**, tool for graving a u-shaped groove. Borers **a** and **c** had been turned counter-clockwise, indicating their use by a left-handed person.*

A different category of manufacturing waste has recently been investigated, particularly by Knut Fladmark and other scholars in Canada: that of microdebitage, the "sawdust" of ancient knappers, comprising tiny flakes of rock, less than a millimeter in size, formed during the process of making stone tools. They are recovered by wet sieving or flotation (Chapter 6), and then examined under the microscope to differentiate them from naturally formed dirt particles. Unlike larger waste products, microdebitage was never cleared away, and therefore serves to pinpoint the location of stoneworking at a site.

Identifying Function: Further Experiments with Stone Artifacts

Experimentation can be used in many other ways to help identify stone tool function. Replicas of almost every ancient stone artifact imaginable have been made and tested – from axes and sickles to grinders and arrowheads. For example, the hand axes of the Lower Paleolithic have long been an enigma, being regarded as all-purpose tools but with much speculation and little controlled experimentation to clarify the issue. Recently, a remarkable test was carried out in England, in which nine replica hand axes, made of flint from the quarries around the important Lower Paleolithic site of Boxgrove, were used by a professional butcher on a roe deer carcass. The experiment showed clearly that the hand axe, used by someone with the relevant skills and knowledge, is an outstanding and versatile butchery tool.

In a study of the many varied objects in France claimed to be Upper Paleolithic stone lamps, Sophie de Beaune used experiment, ethnographic observation of Eskimo lamps, and chemical analysis of the residues found in some of the alleged lamps. She found that only 302 objects were potential lamps, and of these only 85 were definite and 31 others probable. The combustion residues analyzed by spectrometry and chromatography (Chapters 6 and 7) proved to be fatty acids of animal origin, while remains of resinous wood clearly came from the wicks.

Sophie de Beaune tried out replica lamps of various types, with different fuels such as cattle lard and horse grease, and a variety of wicks. The tests left traces of use which corresponded with those in the ancient lamps; and the results were confirmed by study of the Eskimo lighting systems. Tests were also undertaken to determine the amount of light given out by the ancient lamps. They were found to be pretty dim, even in comparison with a modern candle. The power of the light depends on the quality and quantity of fuel; the flame is usually unstable and trembling. Experiments with a stone lamp using horse fat produced a flame of one-sixth the power of a candle, according to measurements with a photometer. But it was found that with only one lamp one can move around a cave, read, and even sew if one is close enough to the light – the eye cannot tell that the flame is weaker than a candle.

Other experiments with stone artifacts attempt to assess the time needed for different tasks. Emil Haury studied the minute beads from prehistoric pueblos in Arizona. One necklace, 10 m (33 ft) in length, had about 15,000 beads, which were an average of only 2 mm (0.08 in) in diameter. Replication, with the perforation done with a cactus spine, led to an estimate of 15 minutes per bead, or 480 working days for the whole necklace. Such exercises help to assess the inherent value of an object through the amount of work involved in its creation.

Assessing the Technology of Stone Age Art

In the field of prehistoric art, a number of analyses can be carried out to determine the pigments and binding medium used, and ancient methods of painting and engraving on stone. In the Upper Paleolithic cave art of southern France and northern Spain, for example, the most usual minerals found have proved to be manganese dioxide (black) and iron oxide (red), though recent analyses in a number of decorated caves have detected the use of charcoal as pigment, which has enabled direct dating to be carried out (p. 144). In the Pyrenees, notably in the cave of Niaux, paint analyses by scanning electron microscopy, X-ray diffraction, and proton-induced X-ray emission (Chapter 9) have suggested the use of specific "recipes" of pigments mixed with mineral "extenders" such as talc which made the paint go further, improved its adhesion to the wall, and stopped it cracking. Analyses have also detected traces of binders in the form of animal and plant oils; in Texas, DNA has been extracted from rock paintings 3000–4000 years old, and seems to come from a mammal, probably an ungulate, presumably in the form of an organic binder.

In a few caves the height and inaccessibility of the art show that a ladder or scaffolding must have been used, and the sockets for a platform of beams still survive in the walls of a gallery in the French cave of Lascaux.

Analysis of pigments from prehistoric paintings in Monitor Basin, Nevada, by X-ray diffraction showed that gypsum had been the binding agent, and that reds and yellows had been made by adding various minerals. All the samples were different, suggesting that the paintings accumulated at different times.

Analysis of Stone Age art by experiment: Michel Lorblanchet draws from memory a copy of a frieze in the cave of Pech Merle, France. The exercise suggested that the entire frieze could have been sketched in only one hour.

It is not always apparent exactly how paint was applied in prehistoric times – whether by brush, pad, finger, or by blowing – but ethnographic observation together with experiments can be of great help in narrowing down the possibilities.

Moreover, infrared film now makes it possible for us to distinguish between ocher pigments. Infrared film sees through red ocher as though it were glass, so that other pigments beneath become visible. In addition, impurities in ocher can be detected since they are not transparent, so that different mixes of paint can be identified. Alexander Marshack used this technique to study the famous "spotted horse" frieze in the cave of Pech Merle, France, and to reconstruct the sequence in which the elements of the panel were painted. He found, for example, that the sets of red dots had been made by different types of ochers, and therefore possibly at different times.

A frieze of black paintings in the same cave led Michel Lorblanchet to an analysis by experiment, in an attempt to discover how long it might have taken to create the frieze. Having studied and memorized every stroke of the composition, he sought out a blank wall area of similar dimensions in a different cave, and drew an exact copy of the frieze on it. This exercise indicated that the entire composition could have been made in only one hour, a fact which underlines the view that much rock art was probably done in intensive bursts by talented artists. More recently, he has also replicated the spotted horse frieze by spitting ocher and charcoal from his mouth; this experiment suggests that the whole frieze could be done in 32 hours, though it was clearly built up in at least four episodes.

The binocular microscope can be used to great effect in the study of engravings on stone, since it can determine the type of tool and stroke used, the differences in width and in transverse section of the lines, and sometimes the order in which the lines were made. Léon Pales, in his study of the Upper Paleolithic engraved plaquettes from the French cave of La Marche, also discovered that if one takes a plasticine or silicone relief-imprint of the engraved surface, the impression shows clearly which lines were engraved after which. The technique proved, for instance, that a supposed "harness" was a secondary feature added to a completed horse's head.

Varnish replicas (see below) of engraved surfaces on stone can also be made, examined in the scanning electron microscope, and compared with surface features produced on experimental engravings. By this method one can study the micromorphology of the engraved lines, see exactly how they were created, in what order, and whether by one tool or several. More recently, new computer advances such as image analysis and 3-D optical surface profiling have been applied to this material since the laser scanner removes the need to have any contact with the often delicate objects or to take replicas of them.

Many other methods of analysis used on stone artifacts have also been applied to other unaltered materials such as bone.

OTHER UNALTERED MATERIALS

Bone, Antler, Shell, and Leather

Since there is usually no difficulty in determining how these raw materials were obtained (except for instance when seashells or a sea mammal's bones are found far inland), the archaeologist's attention focuses on the method of manufacture and function. First, however, one has to be sure that they are humanly made tools.

As with stone tools, it is not always easy to differentiate purposely made artifacts of organic material from accidents of nature. Debate continues about the existence of shaped bone tools before the Upper Paleolithic. Common sense suggests that unshaped bones have been used as tools for as long as stones. After all, even in recent times, as in kill sites in North America (see bison drive box, pp. 292–93), entire bones seem to have been used, unworked, as simple expediency tools during the dismemberment of carcasses.

Similarly, fragile objects such as shells may have perforations that are not necessarily artificial. The American scholar Peter Francis carried out experiments with shells in order to find criteria of human workmanship. Using shells beachcombed in western India, he perforated them in a variety of ways with stone tools: by scratching, sawing, grinding, gouging, and hammering. The resulting holes were examined under the microscope, and it was found that the first three techniques left recognizable traces, whereas gouging and hammering left irregular holes which were difficult to distinguish as artificial – in these cases, one would have to rely on the context of the find, and the position of the perforation (which depends on the shape of the shell), to help one decide whether people were responsible. Italian researcher Francesco d'Errico has established microscopic criteria, by means of experimentation, for differentiating perforations in shell made by natural agents and by humans; and also for recognizing the traces left on bone, antler, and ivory objects by long-term handling, transportation, and suspension.

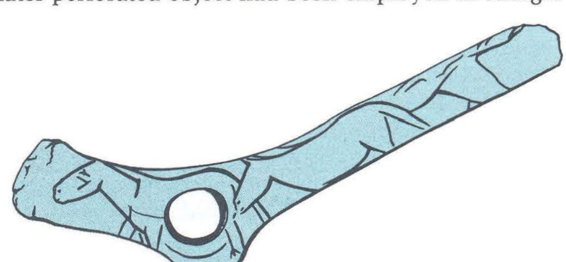
Deducing Techniques of Manufacture. On rare occasions the method of manufacture is clear archaeologically. For example, at the South African site of Kasteelberg, dating to about AD 950, a fabrication area has been discovered where every step in the process of making bone tools can be seen, revealing the complexity, the sequence, and the tools involved. The occupants of this stock-herding site worked in a sheltered spot, using primarily the metapodials (foot bones) of eland and hartebeest. The ends of the bones were removed using a hammerstone and a punch. Next, a groove was pounded along the bone's shaft, and then it was abraded and polished until the shaft was severed. The resulting splinters were shaped with stones (many broken specimens were found discarded), and finally ground and polished into points which are very similar to ethnographic examples known from the San (Bushmen) of the Kalahari Desert.

Microwear studies using the scanning electron microscope combined with experimental archaeology are another successful means of determining methods of bone tool manufacture. Pierre-François Puech and his colleagues have overcome the problem that one cannot place the original tools in the SEM by making varnish replicas of the worked surfaces. A nitrocellulose compound is poured onto the bone, and later peeled off and turned into slide-mounts. They found that experimental marking of bone with various stone tools left characteristic traces which corresponded to marks on prehistoric bone artifacts. Each type of manufacture produced a different pattern of striations. Different methods of polishing bone also left recognizable traces. It is thus becoming possible to reconstruct the history of manufacture of ancient bone artifacts.

Deducing Function. Experimental archaeology and study of wear patterns, either individually or in conjunction with each other, are highly effective in helping us deduce the function as well as the manufacturing techniques of organic artifacts.

One controversial and much-discussed issue is the original function of the perforated antler batons of the European Upper Paleolithic. The orthodox view, based on ethnographic analogy, is that they were arrowshaft-straighteners; but there are at least 40 other hypotheses, ranging from tent pegs to harness pieces. In order to obtain some objective evidence, the French archaeologist André Glory examined the wear patterns in and around the baton perforations. His conclusion was that the wear had definitely been made by the rubbing of a thong or rope of some sort. This result certainly narrows down the list of possible functions. Glory himself used it to bolster his own hypothesis that the batons had been used as handles for slings.

On the other hand, analysis by the American archaeologist Douglas Campana of use-wear in the perforation of a deer shoulder-blade from Mugharet El Wad, Israel, dating to around the 9th millennium BC, suggests that here at any rate a similar if somewhat later perforated object had been employed in straight-



Antler baton from the Upper Paleolithic site of La Madeleine, France. Ethnography suggests that these objects were arrowshaft straighteners, but there are many other theories.

ening wooden shafts. Experimental work supports this conclusion.

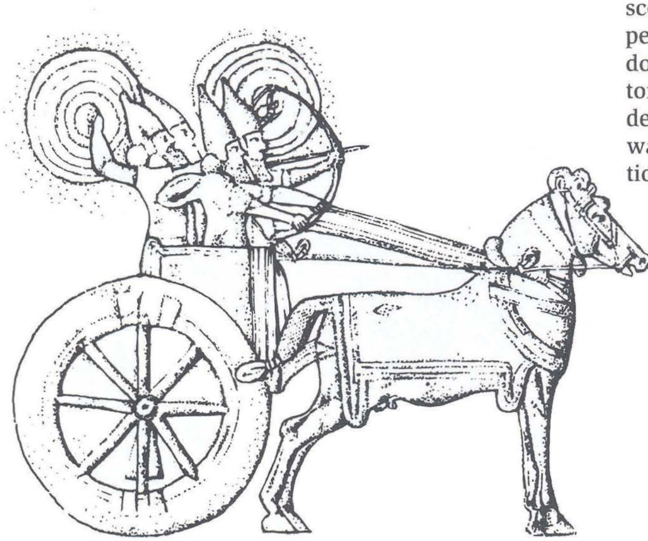
Experiments can likewise be used to help resolve all manner of questions about function and efficiency. Copies have been made, for example, of Upper Paleolithic barbed bone or antler points, and they have been hurled against animal carcasses and other objects. In this way M.W. Thompson was able to demonstrate that the small barbed points, with a central perforation, of the so-called Azilian culture at the end of the Ice Age in southwest Europe were probably toggle harpoons which swiveled and became firmly embedded in their prey. Similarly, replicas have been made of antler projectile points from the Lower Magdalenian period of northern Spain, and were found through experimental use on a dead goat to be highly penetrative and extremely durable, indeed far more so than stone points.

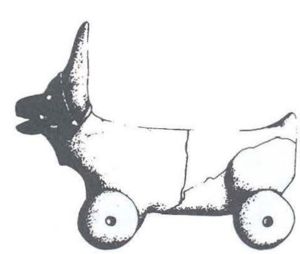
In a replication experiment famous in British archaeological circles, John Coles investigated the efficiency of a leather shield from the Bronze Age of Ireland. It was the only one of its kind to have survived, all others of the period being of bronze. It was found that the shield could be hardened by means of hot water and beeswax, although it retained a degree of flexibility. Coles, armed with the leather replica, and a colleague using a copy of a metal shield, then attacked each other with slashing swords and spears of Bronze Age type. The metal shield was cut to ribbons, indicating that those specimens we have were not functional but for prestige or ritual. The leather shield, on the other hand, was barely perforated by the spear, and received only slight cuts on its outer surface from the sword. Its flexibility had absorbed and deflected the blows. This experiment reveals once again the importance to ancient people of the organic materials that so rarely come down to us intact.

Wood

Wood is one of the most important organic materials, and must have been used to make tools for as long as stone and bone. Indeed, as we have seen, many prehistoric stone tools were employed to obtain and work timber. If wood survives in good condition, it may preserve toolmarks to show how it was worked. As with other materials, one has to distinguish genuine toolmarks from those made by other means. John and Bryony Coles have shown how important it is to differentiate toolmarks from the parallel facets left by beaver teeth. A combination of experiment and direct observation of beaver habits has helped them detect the distinction. As a result, a piece of wood from the Mesolithic site of Star Carr in northern England, thought to have been shaped by stone blades, is now known to have been cut by beaver teeth.

A wide range of wooden tools can survive under special conditions, as we saw in Chapter 2. In the dry environment of ancient Egypt, for instance, numerous wooden implements for farming (rakes, hoes, grain-scoops, sickles), furniture, weapons and toys, and carpentry tools such as mallets and chisels have come down to us. Egyptian paintings such as those in the tomb of the nobleman Rekhmire at Thebes sometimes depict carpenters using drills and saws. But it has been waterlogged wood that has yielded the richest information about woodworking skills (see box overleaf).





Evidence for the wheel. (Left) In the Old World, the spoked-wheel chariot (Assyrian relief, 7th century BC) evolved from the original solid-wheel cart. (Right) In the pre-Columbian New World, the concept of the wheel was known (wheeled model from Veracruz), but full-size wheeled vehicles only arrived with the Spanish, together with the animals needed to pull them.

WOODWORKING IN THE SOMERSET LEVELS

The wetlands in southwest England known as the Somerset Levels preserve a wide range of organic remains, including ancient wooden trackways. John and Bryony Coles, in their long-term Somerset Levels project, have been able to make a remarkably detailed analysis of the woodworking techniques used in track construction.

The chopped ends of pegs and stakes from the tracks often display facets or cutmarks left by the axes used to shape them. Experiments have shown that stone axes bruise the wood and leave dished facets, whereas bronze axes do not cause bruising, but leave characteristic stepped facets in the cuts. Imperfections in the axes – for example nicks in their edges – can also be identified. Such faults have left their signature with each blow of the axe, allowing archaeologists to pinpoint the use of particular axes on particular pieces of wood.

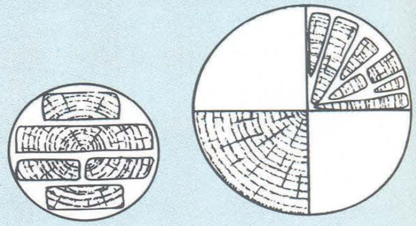
By this method, John and Bryony Coles have been able to prove that at least 10 different axes were used in the construction of one Bronze Age track in the Somerset Levels. Indeed, they have deduced the exact manner of working from these clues. One piece of wood has three facets – the top one's set of ridges is the reverse of the other two. It is therefore clear that the wood was first held vertically, and the axe came down "backhand"; it was then turned more obliquely to the ground, and the axe came down with a forehand stroke.

The large collections of preserved timber from waterlogged areas such as the Somerset Levels, and Flag Fen in eastern England, are enabling archaeologists for the first time to gain insights into prehistoric techniques for splitting, cutting, joining, and piercing wood. It has become apparent that woodcraft changed little through time, even after the arrival of metal tools. For instance, it seems that wood was always split by the wedge-and-mallet method, just as in medieval times.

The Somerset Levels project has also demonstrated that woodlands were being carefully managed at least 5000 years ago. The thin wooden rods used for woven track panels laid flat on the marsh can only have come from the systematic cutting back or coppicing of tree stumps to produce regular crops of young rods.

Experimental felling (below) of an ash tree by John Coles (right) and a colleague, using Neolithic and Bronze Age axes.

Chopped ends of pieces of wood reveal the dished facets produced by a Neolithic stone axe (left), and the angular, stepped facets from a bronze axe (right).



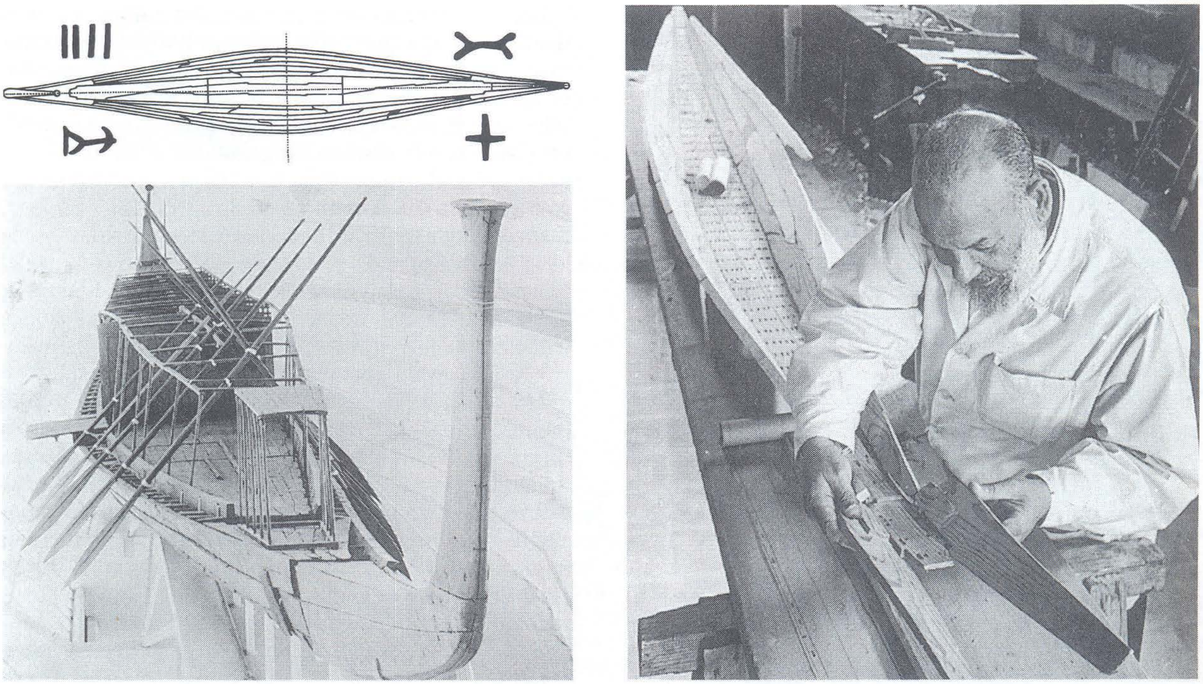
Analysis of the so-called Sweet Track, nearly 6000 years old, showed that Neolithic woodworkers had split large oaks radially into planks (right), but younger trees – too small to be cut radially – had been split tangentially (left).

Bronze Age trackway, *more than 3500 years old, called the Eclipse Track. The excavated length consisted of over 1000 hurdles, short track sections whose interwoven rods could only have been produced from a managed woodland, where tree stumps were deliberately cut back to encourage young, straight shoots.*

Larger wooden objects are not uncommon, such as the Bronze Age tree-trunk coffins of northern Europe, mortuary houses, bridges, waterfront timbers, remains of actual dwellings, and especially a wide range of wheeled vehicles: carts, wagons, carriages, and chariots. Until the Industrial Revolution and the arrival of railways and motor vehicles, all wheeled transport was made of wood, with metal fittings in later periods. A surprising number of vehicles (e.g. entire ox-wagons in the Caucasus) or of recognizable parts (especially wheels) have survived, as well as evidence in models, art, and literature. In the pre-Columbian New World, wheeled models are the only evidence: wheeled vehicles as such were not introduced until the Spanish Conquest, along with the beasts of burden needed to pull them. In the Old World, most finds are vehicles buried in graves. Wheeled vehicles first appeared in the 4th millennium BC in the area between the Rhine and the Tigris; the earliest wheels were solid discs, either single-piece (cut from planks, not transverse slices of tree-trunks) or composite. Spoked wheels were developed in the 2nd millennium for lighter, faster vehicles such as chariots, for instance ones found in Tutankhamun's tomb (see box, pp. 62–63). Wheeled transportation clearly had a huge impact on social and economic development, but nevertheless had a very limited geographical spread when compared with the ubiquitous wooden technology displayed in watercraft.

Investigating Watercraft. Until the 19th century all boats and ships were made predominantly of wood, and in perhaps no other area of pre-industrial technology did the world's craftspeople achieve such mastery as in the building of wooden vessels of all kinds, from small riverboats to great oceangoing sailing ships. The study of the history of this technology is a specialized undertaking, far beyond the scope of the present book to summarize in any detail. But it would be wrong to imagine that the archaeologist has little to contribute to what is already known from historical records. For the prehistoric period such records are of course absent, and even in historic times there are great gaps in knowledge that archaeology is now helping to fill.

The richest source of archaeological evidence is the preserved remains of ships uncovered by underwater archaeology (box, p. 95). In the late 1960s, the excavation of a 4th-century BC Greek ship off Kyrenia, Cyprus, showed that vessels of that period were built with planks held together by mortise-and-tenon joints. The recent excavation by George Bass and his colleagues of a wreck at Uluburun, near Kaş, off the south coast of Turkey (box, pp. 374–75), has now revealed a vessel 1000 years older that uses the same technique.



Reconstructing the oldest ship in the world. In 1954 the dismantled parts of a cedarwood boat were found buried in a pit on the south side of the Great Pyramid of King Cheops at Giza, Egypt. (Top left) One important clue to the reconstruction proved to be the four classifying signs, marked on most of the timbers, that indicated to which of the four quarters of the ship the timbers belonged. (Right) Hag Ahmed Youssef used a scale model to help in the task of reconstruction. (Left) After 14 years of work, the 1244 pieces of the ship were finally reassembled.

At the beginning of this chapter we stressed how important it is for archaeologists to obtain the advice of craftspeople in the technology concerned. This is particularly true for the accurate understanding of shipbuilding. J. Richard Steffy, of the Institute of Nautical Archaeology in Texas, has an unrivaled practical knowledge of the way ships are (or were) put together, a knowledge he has applied to excavated vessels in the Old World and the New. In his judgment the best way to learn how a ship was built and functioned is to refit the excavated timbers in the most likely original shape of the vessel, achieved through analysis of the excavation and painstaking trial and error, with the aid of exact copies at one-tenth scale of the remaining timbers (box, pp. 96–97). This was the procedure adopted by another craftsman, the Egyptian Hag Ahmed Youssef, in his 14-year rebuilding of the dismantled ship of the pharaoh Cheops found at Giza, at 4500 years the oldest known ship in the world.

The next step in any assessment of a ship's construction techniques and handling capabilities is to build either a full-size or a scale replica, preferably one that can be tested on the water. Replicas based on excavated remains, such as the replica Viking *knarr* or cargo ship that sailed around the world in 1984–86, are more likely to produce scientifically accurate results than those built only from generalized artistic depictions, as in the case of replicas of the ships of Columbus. But the building of replicas based on depictions can still be immensely valuable. Until some British scholar-enthusiasts, led by J.F. Coates and J.S. Morrison, actually constructed and tested a replica of an ancient Greek trireme, or warship, in 1987, virtually nothing was known about the practical characteristics of this important seacraft of Classical antiquity.

Another contribution archaeology can make to seafaring studies is to demonstrate the presence of boats even where no ship remains or artistic depictions exist. The simple fact that people crossed into Australia at least 50,000 years ago – when that continent was cut off from the mainland, even if not by so great a distance as it is today – suggests that they had craft capable of covering 80 km (50 miles) or more. Similarly, the presence of obsidian from the Aegean islands on the Greek mainland 10,000 years ago shows that people at that time had no difficulty in sailing to and from the islands.

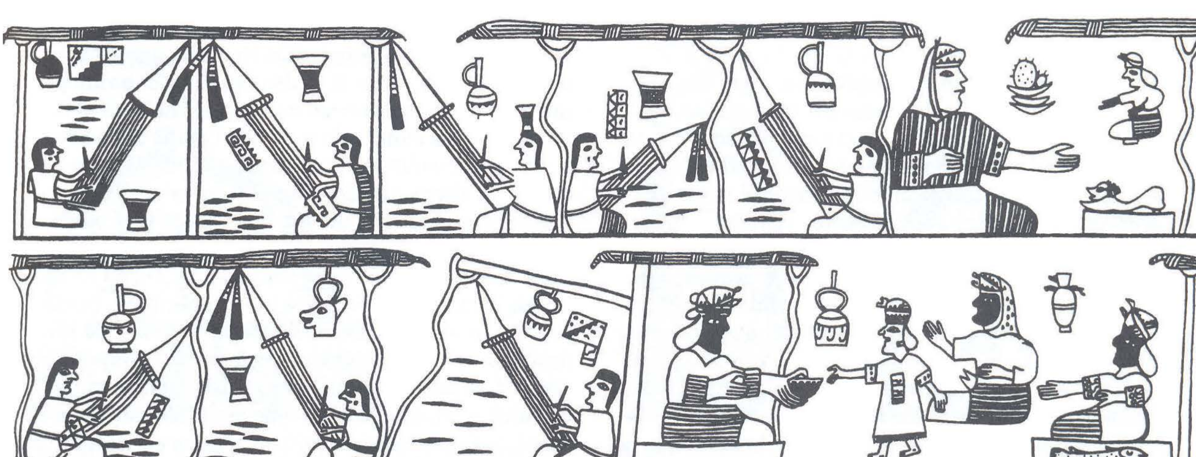
Plant and Animal Fibers

The making of containers, fabrics, and cords from skins, bark, and woven fibers probably dates back to the very earliest archaeological periods, but these fragile materials rarely survive. However, as we saw in Chapter 2, they do often survive in very dry or wet conditions. In arid regions, such as Egypt or parts of the New World, such perishables have come down to us in some quantity, and the study of ***basketry and cordage*** there reveals complex and sophisticated designs and techniques that display complete mastery of these organic materials.

Waterlogged conditions can also yield a great deal of fragile evidence. Well-preserved workshops such as those of Viking York have taught us much about a variety of crafts in England in the 10th century AD. Dyestuffs, including madder root, woad, and quantities of dyer's greenweed were all represented by macrofossils. This interpretation was confirmed by chemical analysis of samples of Viking textiles from the excavations. Chromatography (Chapters 6 and 7) identified a range of dyes in the textiles, again including madder and woad. Original dye colors can be identified from their "absorption spectra," the wavelengths of light they absorb: it has been found that the Romans in Britain often wore purple, while the York Vikings liked red. Clubmoss, also represented by macrofossils, was probably used as a mordant at York, fixing madder reds and greenweed yellows directly on to the textile fibers. All the animal fibers were wool or silk, while all those of vegetable origin which could be determined were flax. Evidence for the cleaning of sheep's wool came with the discovery of adults and puparia of the sheep ked, a wingless parasitic fly, and also sheep lice.

Analyzing Textiles. Where textiles are concerned, the most crucial question is how they were made, and of what. In the New World, a certain amount of information on pre-Columbian weaving methods is available from ethnographic observation, as well as from Colonial accounts and illustrations, from depictions on Moche pottery, and from actual finds of ancient looms and objects (spindles and shuttles of wood, bone, or bamboo) found preserved in the Peruvian desert. There seem to have been three main types of loom: two were fixed (one vertical, the other horizontal), and used for really big pieces of weaving, while a small portable version was used for items such as clothing or bags.

The richest New World evidence, however, comes from Peruvian textiles themselves, which have survived in an excellent state of preservation thanks to the aridity of much of the country. The Andean cultures mastered almost every method of textile weaving or decoration now known, and their products were often finer than those of today – indeed, were some of the best ever made. By about 3000 BC they had developed cotton textiles, which quickly took over from the previous techniques using fibers (such as reeds and rushes)



New World textiles. Some of the finest woven designs ever made have come from Peru. This scene from the rim of a Moche vase depicts a Peruvian cloth factory. Eight women are shown weaving at their portable, backstrap looms, supervised by the official top right. The meaning of the panel at lower right is not known.

that were far less supple and resistant. The Peruvians also came to use animal fibers from their domesticated camelids, particularly the vicuña and the alpaca. They had an extraordinary range of dyes: the huge textiles from the Nazca culture, dating to the 1st millennium AD, have up to 190 different color tones.

The precise weaving technique can often be deduced through careful observation by specialists. Sylvia Broadbent has studied some painted cotton fabrics of the pre-Hispanic Chibcha culture of Colombia, and has been able to ascertain that they are all woven of "one-ply S-twist cotton in a basic plainweave, single wefts over double warp threads." Counts of the number of threads range from 6 to 12 wefts (side to side) per centimeter, and from 11 to 14 warps (up/down) per centimeter. At the weft edge, the weft threads turn in groups rather than singly, a fact which implies the use of a weaving technique involving multiple shuttles. The end of the weaving was secured by a row of chain-stitch.

It is also thanks to aridity that we have so many surviving textiles from ancient Egypt. Here, as in Peru, we can learn a great deal from surviving equipment and from models such as that found in the tomb of Meketre at Thebes (2000 BC) which shows a weaving workshop with a horizontal or ground loom as well as spindles and other tools. Flinders Petrie's excavation at Kahun, a town site for workers building a pyramid, dating to about 1890 BC, revealed weaver's waste on the floor of some houses: scraps of unspun, spun, and woven threads, colored red and blue. Analysis in the scanning electron microscope proved them to be from sheep's wool, while dye tests showed that madder was used for red, and the blue probably came from the plant *Indigofera articulata*.

The wrappings of a male Egyptian mummy of 170 BC in Pennsylvania University Museum (designated PUM II) also underwent scanning electron microscopy, and proved to be a fabric of fine threads, whose straightness and markings were identical to modern flax fibers: that is, the wrappings were a linen fabric.

But it is not only from Peru and Egypt that we have evidence for textiles. They can survive in waterlogged conditions, as we saw at Viking York, and even where preservation is less good, careful excavation may yield textile remains, as in the Celtic chieftain's tomb at Hochdorf, western Germany, dating to about 550 BC. Here analysis of the remains using a scanning electron microscope showed that the chieftain's death-bed had been covered with woven textiles made from spun and twisted threads of hemp and flax. There were also coverings made of sheep's wool, horse hair, and badger wool, and furs of badger and weasel were present as well. In the SEM, the hair of different species can be identified if the diagnostic cuticle pattern is preserved, as in this case.

The oldest known trace of cloth was found recently in the form of a white linen fragment clinging to the handle of an antler tool from Çayönü, Turkey. Dating to about 7000 BC, it was probably made of flax. However, far older evidence of weaving has been found at Pavlov, Czech Republic, dated to between 25,000 and 27,000 years ago, in the form of impressions of textiles or flexible basketry on fired clay.

Microwear Analysis of Fibers. The analysis of microwear is chiefly associated with stone and bone tools, as shown above; but it has recently been applied with great success to textiles and fibers. Research at the University of Manchester's Department of Textiles using the SEM has shown that different kinds of fracture, damage, and wear leave diagnostic traces on different classes of fibers. Tearing or bursting leave a very different pattern from the prolonged flexing associated with fatigue and breakdown of the fibers – the latter produce longitudinal damage, resulting in the fibers having "brush ends." Cutting of fibers is easy to identify in the SEM, and razor-marks are readily distinguishable from those made by shears or scissors (see also Lindow Man box, pp. 448–49).

In an interesting application of their technique, the Manchester researchers examined two woollen items from the Roman fort of Vindolanda, northern England. For the first, a soldier's leg bandage, they had to determine whether it had been discarded because it was worn out, or whether it had been damaged by its prolonged burial. Analysis showed an abundance of "brush ends" indicating that the bandage had been much used, but there was also evidence of postdepositional damage (transverse fractures). The second item, an insole for a child's shoe, seemed to the naked eye to be in mint condition. However, in the SEM it became clear that there was considerable wear of the surface fibers, implying that the unused insole had been cut from a heavy fabric (perhaps a cloak) that was already quite worn.

This technique obviously holds enormous promise for future analyses of those fabrics that have come down to us. Even where textiles do not survive, they sometimes leave an impression behind, for example on mummies, from which the type of weave can be recognized. And similarly useful information can be derived from the study of imprints of fabrics, cordage, and basketry that are found on fired clay, by far the most abundant of the synthetic materials available to the archaeologist.

SYNTHETIC MATERIALS

Firing and Pyrotechnology

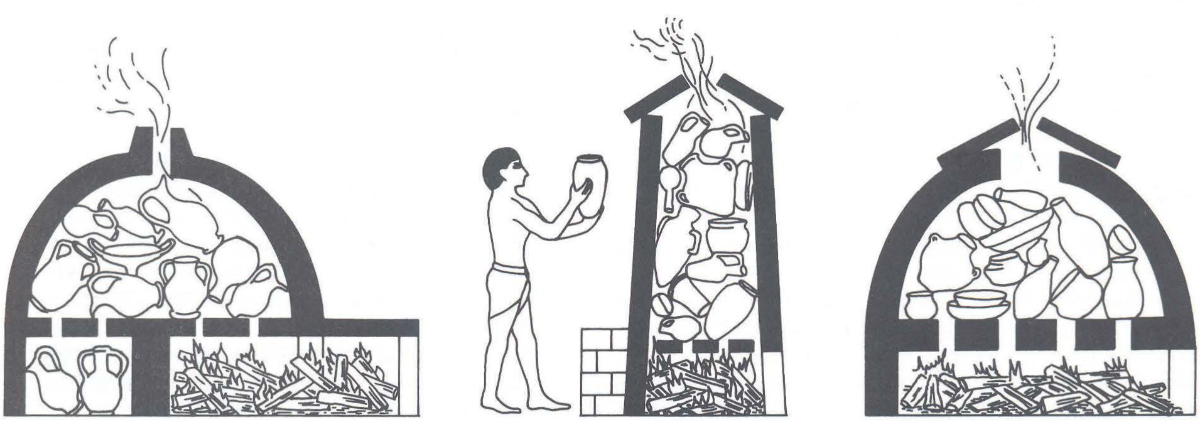
It is possible to consider the whole development of technology, as far as it relates to synthetic materials, in terms of the control of fire: pyrotechnology. Until very recent times, nearly all synthetic materials depended upon the control of heat; and the development of new technologies has often been largely dependent upon achieving higher and higher temperatures under controlled conditions.

Clearly the first step along this path was the mastery of fire, possible evidence for which already occurs in the Swartkrans Cave, South Africa, in layers dating to 1.5 million years ago (Chapter 6). Cooked food and preserved meat then became a possibility, as did the use of heat in working flint (see above), and in hardening wooden implements like the yew spear from the Middle Paleolithic site of Lehringen, Germany.

Terracotta (baked clay) figurines were produced sporadically in the Upper Paleolithic period at sites from the Pyrenees and North Africa to Siberia, but their most notable concentration occurs in the Czech Republic at the open-air sites of Dolní Věstonice, Pavlov, and Předmostí, dating to about 26,000 years ago: they comprise small, well-modeled figurines of animals and humans. Recent analysis reveals that they were modeled in wetted local loess soil, and fired at temperatures between 500°C and 800°C (932–1472°F). The figurines were concentrated in special kilns, away from the living area. Almost all are fragmentary, and the shape of their fractures implies that they were broken by thermal shock – in other words, they were placed, while still wet, in the hottest part of the fire, and thus deliberately caused to explode. Rather than carefully made art objects, therefore, they may have been used in some special ritual.

A significant development of the Early Neolithic period in the Near East, around 8000 BC, was the construction of special ovens used both to parch cereal grains (to facilitate the threshing process) and to bake bread. These ovens consisted of a single chamber in which the fuel was burnt. When the oven was hot the fuel was raked out and the grain or unbaked bread placed within. This represents the first construction of a deliberate facility to control the conditions under which the temperature was raised. We may hypothesize that it was through these early experiences in pyrotechnology that the possibility of making pottery by firing clay was discovered. Initially pottery was made by firing in an open fire. "Reducing" conditions (the removal of oxygen) could be achieved by restricting the flow of air, and by adding unburnt wood.

These simple procedures may well have been sufficient in favorable cases to reach temperatures equivalent to the melting point of copper at 1083°C (1981°F). Given that copper was already being worked by cold hammering, and then by annealing (see below), and some copper ores such as azurite were used as



Pyrotechnology: the control of fire. Initially pottery was made in an open fire. The introduction of the potter's kiln meant higher temperatures could be achieved, also spurring on the development of metallurgy. (Left) Mesopotamian dome-shaped kiln of the early 4th millennium BC, built largely of clay, with an outer wall of stone or mud brick. (Center) Egyptian kiln of c. 3000 BC reconstructed from tomb paintings. The potter may have stood on the small platform to load the kiln. (Right) Greek kiln of c. 500 BC, reconstructed from scenes on Corinthian plaques: the extended fire opening probably improved combustion.

pigments, it was to be expected that the smelting of copper from its ores and the casting of copper would be discovered. Potters' kilns, where there is a controlled flow of air, can produce temperatures in the range of 1000–1200°C (1832–2192°F), as has been documented for such early Near Eastern sites as Tepe Gawra and Susa, Iran, and the link between pottery production and the inception of copper metallurgy has long been noted. Bronze technology subsequently developed with the alloying primarily of tin with copper.

Iron can be smelted from its ores at a temperature as low as 800°C (1472°F), but in order to be worked while hot, it requires a temperature of between 1000 and 1100°C (1832–2012°F). In Europe and Asia, iron technology developed later than copper and bronze technology because of problems of temperature control and the need for stricter control of reducing conditions. In central and southern Africa, however, the technology of bronze does not appear to antedate that of iron. In the New World, iron was not worked in pre-Columbian times. For iron to be cast, as opposed to worked while hot, its melting point has to be reached (1540°C, 2804°F), and this was not achieved until *c.* 500 BC in China.

There is thus a logical sequence in the development of new materials governed largely by the temperature attainable. In general the production of glass and faience – a kind of "pre-glass," see below – is first seen very much later in an area than that of pottery, since a higher temperature and better control are needed. They appear with the manufacture of bronze.

The study of the technology used to produce synthetic materials such as these naturally requires an understanding of the materials and techniques employed. Traditional crafts, for instance as observed today in many Near Eastern bazaars, can give valuable clues as to the way artifacts may have been made, and to the technical procedures carried out.

Pottery

We saw above that throughout the earlier periods of prehistory containers made of light, organic materials were probably used. This does not mean, as has often been assumed, that Paleolithic people did not know how to make pottery: every fire lit on a cave floor will have hardened the clay around it, and we have already noted that terracotta figurines were sometimes produced. The lack of pottery vessels before the Neolithic period is mainly a consequence of the mobile way of life of Paleolithic hunter-gatherers, for whom heavy containers of fired clay would have been of limited usefulness. The introduction of pottery generally seems to coincide with the adoption of a more sedentary way of life, for which vessels and containers that are durable and strong are a necessity.

The almost indestructible potsherd is as ubiquitous in later periods as the stone tool is in earlier ones – and just as some sites yield thousands of stone tools, others contain literally tons of pottery fragments. For a long time, and particularly before the arrival of absolute dating methods, archaeologists used pottery primarily as a chronological indicator (Chapter 4) and to produce typologies based on changes in vessel shape and decoration. These aspects are still of great importance, for example in assessing sites from surface surveys (Chapter 3). More recently, however, as with stone tools, attention has shifted toward identifying the sources of the raw materials (Chapter 9); the residues in pots as a source of information about diet (Chapter 7); and above all to the methods of manufacture, and the uses to which vessels were put.

Where manufacture is concerned, the principal questions one needs to address can be summarized as: What are the constituents of the clay matrix? How was the pot made? And at what temperature was it fired?

Pot Tempers. Simple observation will sometimes identify the inclusions in the clay that are known as its temper – the filler incorporated to give the clay added strength and workability and to counteract any cracking or shrinkage during firing. The most common materials used as temper are crushed shell, crushed rock, crushed pottery, sand, grass, straw, or fragments of sponge. Experiments by the American scholars Gordon Bronitsky and Robert Hamer have demonstrated the qualities of different tempers. They found that crushed burnt shell makes clay more resistant to heat shock and impact than do coarse sand or unburnt shell; fine sand is the next best. The finer the temper, the stronger the pot; and the archaeological record in parts of the New World certainly shows a steady trend toward finer tempers.

How Were Pots Made? The making or "throwing" of pots on a wheel or turntable was only introduced after 3400 BC at the earliest (in Mesopotamia). The previous method, still used in some parts of the world, was to build the vessel up by hand in a series of coils or slabs of clay. A simple examination of the interior and exterior surfaces of a pot usually allows one to identify the method of manufacture. Wheelthrown pots generally have a telltale spiral of ridges and striations which is absent from handmade wares. These marks are left by the fingertips as the potter draws the vessel up on the turntable. Impressions can also be left on the outer

Evidence for pot-making using a wheel. An Egyptian potter shapes a vessel on the turntable type of wheel in this limestone portrait of c. 2400 BC.

surface of pots by the flat paddles – sometimes wrapped in cloth, which also leaves its mark – which were used to beat the paste to a strong, smooth finish.

How Were Pots Fired? The firing technique can be inferred from certain characteristics of the finished product. For example, if the surfaces are vitrified or glazed (i.e. have a glassy appearance), the pot was fired at over 900°C (1652°F) and probably in an enclosed kiln. The extent of oxidization in a pot (the process by which organic substances in the clay are burned off) is also indicative of firing methods. Complete oxidization produces a uniform color throughout the paste. If the core of a sherd is dark (grey or black), the firing temperature was too low to fully oxidize the clay, or the duration of the firing was insufficient, factors which often point to the use of an open kiln. Open firing can also cause blotchy surface discolorations called "fire clouds." Experimental firing of different pastes at different temperatures and in various types of kiln provides a guide to the colors and effects that can be expected.

An exact approach to firing temperature was used by the American scholars W.D. Kingery and Jay Frierman on a sherd of graphite ware from the Copper Age site of Karanovo, Bulgaria. Their method entailed reheating the specimen until irreversible changes occurred in its microstructure, thus placing a ceiling on the temperature at which it could originally have been fired. Examination by scanning electron microscopy revealed a slight change in microstructure after firing at 700°C (1292°F) in a carbon-dioxide atmosphere; marked changes occurred after one hour at 800°C (1472°F), while the clay vitrified at 900°C (1652°F). They could thus conclude that the graphite ware was originally fired at a temperature below 800°C, and most probably at about 700°C. Such results contribute greatly to our assessment of the technological capabilities of different cultures, particularly as regards their possible mastery of metallurgy (see below).

The archaeology of kiln sites has contributed much to our knowledge of firing procedures. In Thailand, for example, high-fired or "stoneware" ceramics were in mass production from the 11th to the 16th centuries AD, and traded around Southeast Asia and to Japan and western Asia; yet contemporary texts say nothing about the industry. Australian and Thai archaeologists and scientists on this project found that two cities, Sisatchanalai and Sukhothai, were the most important production centers, and excavation of the villages around the former has revealed hundreds of large kilns, often built on earlier collapsed specimens, sometimes to a depth of 7 m (23 ft). This stratigraphy of kiln-types has shown the development of their design and construction – from the early, crude, clay forms to the technically advanced brick ones that could achieve the higher firing temperatures needed for the fine exported wares. The later kilns were built on mounds that kept them away from wet soil, ensuring production throughout the year, and reflecting the increasing demands being made on the industry.

Evidence from Ethnography. Unlike the making of stone tools, the production of pottery by traditional methods is still widespread in the world, so it is profitable to pursue ethnoarchaeological studies not only on the technological aspects but also from the social and commercial points of view. Among many successful projects, one could cite the long-term work of the American archaeologist Donald Lathrap among the Shipibo-Conibo Indians of the Upper Amazon (eastern Peru). Here the modern ceramic styles can be traced back to archaeological antecedents of the 1st millennium AD. Most of the women are potters, each producing vessels primarily for her own household, both for cooking and for other purposes such as storage. The pots are made of local clays, with a variety of tempers including ground-up old potsherds, but other minerals and pigments are imported from neighboring regions for slips and decorative work. The pots are built up with coils of clay. Though a year-round activity, potmaking tends to occur mostly in the dry season, from May to October. Studies such as these are useful for a wide range of questions: not only how pots are made, when, why, and by whom, but also how much time and effort are invested in different types of vessels; how often and in what circumstances they get broken; and what happens to the pieces – in other words, patterns of use, discard, and site-clearance.

Archaeologists can thus derive many valuable insights from ethnoarchaeological work. Historical sources and artistic depictions from a number of cultures provide supplementary data.

Faience and Glass

Glassy materials are relative latecomers in the history of technology. The earliest was *faience* (a French word derived from Faenza, an Italian town), and might be called a "pre-glass"; it was made by coating a core material of powdered quartz with a vitreous alkaline glaze. Originating in predynastic Egypt (before 3000 BC), it was much used in dynastic times for simple beads and pendants. Faience's main importance to archaeology has been in the evidence it can provide for the provenience or source of particular beads, through analysis of their composition, and hence in helping to assess how dependent the technology of prehistoric Europe was on Egypt and the eastern Mediterranean.

Neutron activation analysis (box, pp. 360–61), which can trace elements down to concentrations of a few parts per million, has been applied to Bronze Age faience beads, and proved that those from England had a relatively high tin content which made them clearly different from those from the Czech Republic (which have high cobalt and antimony) and even from those from Scotland. All these groups were distinct from Egyptian beads, thus underlining the existence of local manufacture of this class of artifact.

By about 2500 BC Mesopotamia was making the first beads of real *glass*, which seem to have been highly prized. Once it had been discovered, glass was easy and cheap to make: it simply involves melting sand and cooling it again; the liquid cools without crystallizing, and therefore remains transparent. The problem to be overcome was the high melting point of silica (sand) – 1723°C (3133°F) – but if a "flux" such as soda or potash is added, the temperature is lowered. Soda lowers it to 850°C (1562°F), but the result is rather poor-quality glass. By trial and error, it must have been discovered that also adding lime produces a better result: the optimum mix is 75 percent silica, 15 percent soda, and 10 percent lime. As we have seen, glass can only have been made after the means of generating very high temperatures had been achieved; this occurred in the Bronze Age with the development of charcoal furnaces for smelting metal (see below).

The first real glass vessels have been found in sites of the Egyptian 18th Dynasty, *c.* 1500 BC; the earliest known glass furnace is that at Tell el-Amarna, Egypt,

Roman glass from northern Italy. The Romans introduced the technique of glass-blowing in about 50 BC, and created some of the finest pieces ever made. Their expertise was not matched until Venetian work of Renaissance times.

dating to 1350 BC. Vessels were made using a technique like the lost-wax method (see below): molten glass was fashioned around a clay core, which was scraped out once the glass had cooled. This leaves a characteristic rough, pitted interior. Statuettes and hollow vessels were also made in stone or clay molds.

By 700 BC all the principal techniques of making glass had been developed (producing vessels, figurines, windows, and beads) except for one: glass-blowing, which involves inflating a globule of molten glass with a metal tube, or sometimes blowing it into a mold. This quick and cheap method was finally achieved in about 50 BC by the Romans, whose expertise with glass was not equaled until the heyday of glasswork in Venice during the 15th and 16th centuries AD. Moreover, the Romans' output of glass was not matched until the Industrial Revolution. Why, then, is ancient glass so rare? The answer is not, as one might imagine, because it is fragile – it is often no more fragile than pottery – but because, like metals and unlike pottery, it is a reusable material, with fragments being melted down and incorporated into new glass.

Once again, *composition* and *production* are the keynotes of the archaeological approach to these materials. Until recent decades it was very hard to determine the exact raw materials used, since crystallographic observation provided no clues. In the last 30 years, however, new techniques have enabled specialists to analyze the constituents of a variety of ancient glasses. E.V. Sayre and R.W. Smith, for example, undertook research to find systematic compositional differences in ancient glasses by analyzing them for 26 elements through a combination of three techniques: flame photometry, colorimetry, and above all optical emission spectrometry (Chapter 9). As a result, several categories of ancient glass were established, each with a different chemical composition. For instance, specimens of the 2nd millennium BC (primarily from Egypt, but also from throughout the Mediterranean area) were a typical soda-lime glass with a high content of magnesium. Specimens of the final centuries BC (from Greece, Asia Minor, and Persia) were rich in antimony, and had a lower content of magnesium and potassium. Roman glass proved to have less antimony and more manganese than the others.

Other methods which have been applied to ancient glass include the electron microbeam probe, which is a refinement of the non-destructive X-ray fluorescence technique (Chapter 9) and which can be used on tiny specimens. Neutron activation analysis can also be used in glass analysis.

Flaws in the glass such as bubbles can sometimes, by their size, shape, orientation, and distribution, inform the specialist how the specimen was handled from crucible to final shaping. By-products, too, can be informative. A "broken bead" from the Iron Age Meare lake village, southwest England, may actually be a mold for making glass beads.

ARCHAEOMETALLURGY

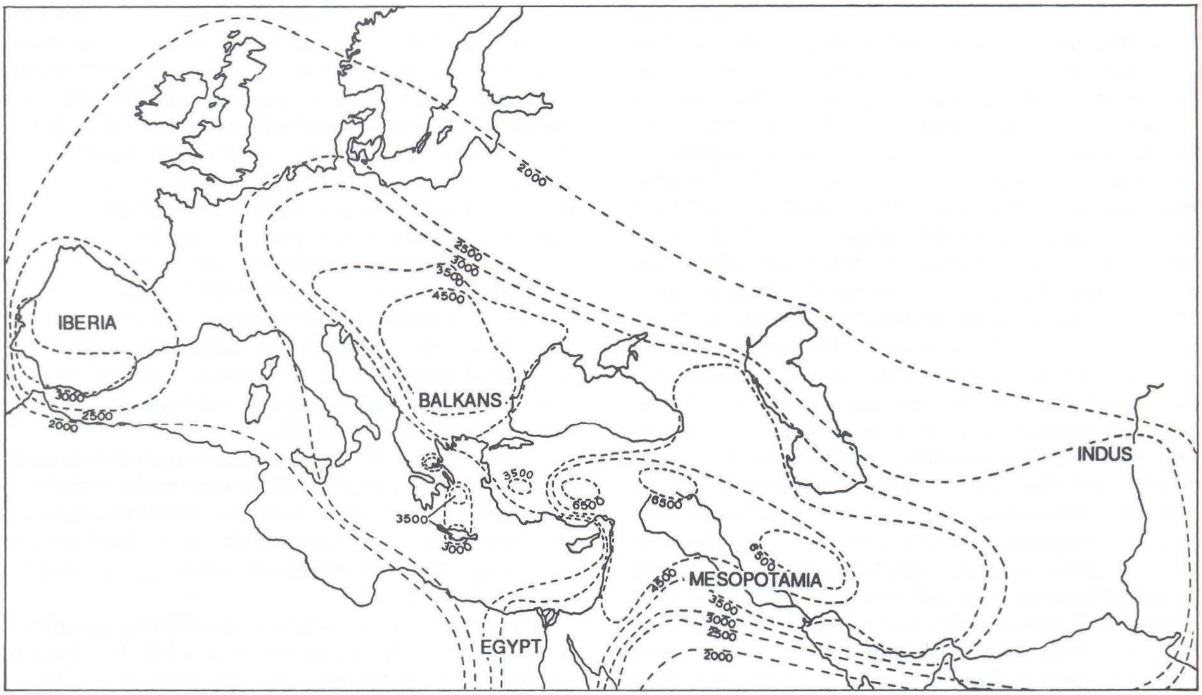
Non-Ferrous Metals

The most important non-ferrous metal – that is one not containing iron – used in early times was copper. In due course it was learnt that a harder, tougher product could be made by alloying the copper with tin to make bronze. Other elements, notably arsenic and antimony, were sometimes used in the alloying process; and in the later Bronze Age of Europe it was realized that a little lead would improve the casting qualities.

Gold and silver were also important, and lead should not be overlooked. Other metals such as tin and antimony were used only rarely in metallic form.

In most areas where copper and bronze were produced there was a natural progression, depending mainly on temperature, analogous to that for synthetic materials in general (see above). A basic understanding of these processes is fundamental to any study of early technology:

1. ***Shaping native copper:*** Native copper (metallic copper found in that form in nature, in nuggets) can be hammered, cut, polished, etc. It was much used in the "Old Copper" culture (4th–2nd millennium BC) of the Archaic period in the northern United States and Canada, and makes its appearance in the Old World at such early farming sites as Çatalhöyük and Çayönü in Turkey and Ali Kosh in Iran by 7000 BC.
2. ***Annealing native copper:*** Annealing is simply the process of heating and hammering the metal. Hammering alone causes the metal to become brittle. This process was discovered as soon as native copper began to be worked.
3. ***Smelting the oxide and carbonate ores of copper***, many of which are brightly colored.
4. ***The melting and casting of copper***, first in a single (open) mold, and later in two-piece molds.
5. ***Alloying with tin (and possibly arsenic)*** to make bronze.



The origins of European copper metallurgy. Traditionally, the techniques of metalworking were seen to have spread to Europe from the more advanced lands of the Near East. But a somewhat different conclusion arises from studies of the early history of copper smelting in the Balkans and elsewhere. If one uses the calibrated radiocarbon chronology to draw a map where lines or "isochrons" indicate the earliest dates for metallurgy in each area, it becomes apparent that there were quite possibly three – not one – independent centers of origin: the Near East, the Balkans, and perhaps Spain and Portugal (Iberia).

6 ***Smelting from sulphide ores***, a more complicated process than from carbonate ores.
7 ***Casting by the lost-wax ("cire perdue") process*** (see below) and use of the casting-on process, where most complicated shapes are produced by casting in several stages.

Lead has a melting point of 327°C (620°F) and is the most easily worked of metals. It can be smelted from its ores at around 800°C (1472°F). Silver melts at 960°C (1760°F), gold at 1063°C (1945°F), and copper at 1083°C (1981°F). So that in general, when craftspeople had mastered copper and bronze technology, they were also adept in working gold and silver and, of course, lead.

The techniques of manufacture of artifacts made from these materials can be investigated in several ways. The first point to establish is ***composition***. Traditional laboratory methods readily allow the identification of major constituents. For instance, the alloys present in bronze may be identified in this way. However, in practice it is now more usual to utilize the techniques of trace element analysis which are also used in characterization studies (Chapter 9). For many years optical emission spectrometry (OES) was very widely used, but it has increasingly been superseded by atomic absorption spectrometry. X-ray fluorescence (XRF) is also often utilized, as on ceramic paste or glass. These methods are all reviewed in Chapter 9.

The other essential approach is that of ***metallographic examination***, when the structure of the material is examined microscopically (see box opposite). This will determine whether an artifact has been formed by cold-hammering, annealing, casting, or a combination of these methods.

Turning to the sequence of stages outlined above, the use of native copper may be suspected when the copper is very free of impurities. And it can certainly be confirmed when the copper has not been melted and cast, for metallographic examination will then show that the artifact has been shaped only by cold-hammering or annealing. For example, when the American metallurgist Cyril Smith subjected a copper bead of the 7th millennium BC from Tepe Ali Kosh,

METALLOGRAPHIC EXAMINATION

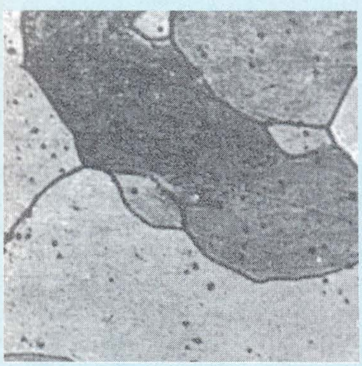
One of the most useful techniques for the study of early metallurgy is that of metallographic examination. It involves the examination under the light microscope of a polished section cut from the artifact, which has been chemically etched so as to reveal the metal structure. Since one cannot make translucent sections, it is necessary to direct reflected light to the object's surface (unlike petrographic study, for instance in the examination of pottery, where a thin section is usually examined in transmitted light).

The microscopic examination of metal structures can be highly informative, not only in distinguishing major phases in the manufacturing history of the artifact (such as casting on), but in the detection of more subtle processes.

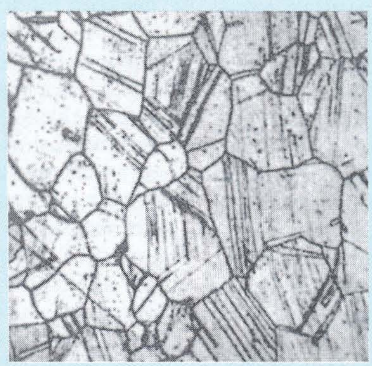
In the case of copper, for instance, it is possible to recognize when the artifact has been worked from native copper. The structure will also clearly reveal whether or not the copper has been cold-worked, and whether or not it has been annealed (a process which entails heating and cooling the metal to toughen it and reduce brittleness). Indeed the whole history of the treatment of the material can be revealed, showing successive phases of annealing and cold-working.

Metallographic examination can be just as revealing in the cases of iron and steel. Wrought iron is easily recognizable: crystals of iron and streaks of slag can be clearly seen. The results of carburization – for instance, after part of an iron object has been heated in charcoal to give a hard cutting edge – are also very clear. The dark-etched harder edge is quite distinct from the softer white inner part.

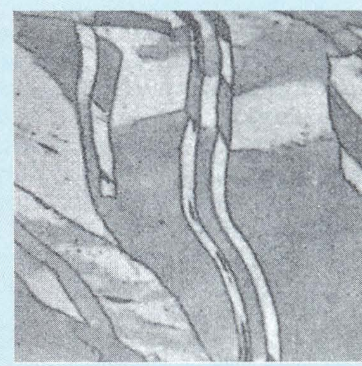
Metallographic examination can thus furnish much information about the manufacturing process, and can reveal the very considerable mastery which many smiths exercised over their craft.



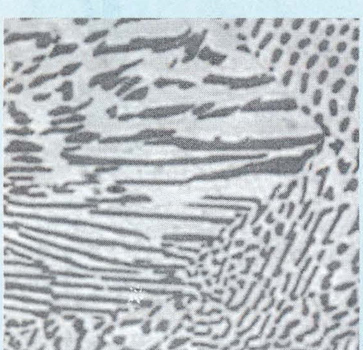
Copper *– cast and fully annealed. Magnification x100.*



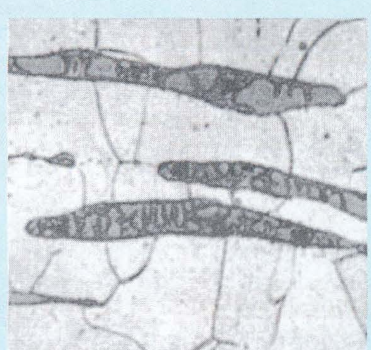
The slip-bands *(straight lines) indicate that the copper has been cold-worked (x100).*



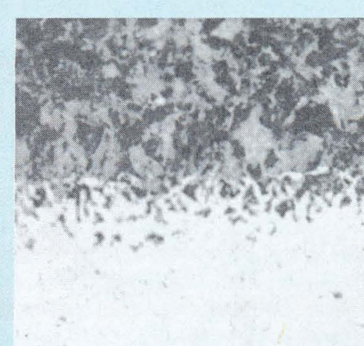
Copper *that has been worked, fully annealed, and cold-worked again (x150).*



Silver *that has been super-saturated with copper (x100).*



Wrought iron *at x200. The light grain is iron, the darker material slag.*



Iron *that has been partially hardened. The dark structure is harder than the lighter.*

Iran, to microscopic and metallographic examination, he found that a naturally occurring lump of copper had been cold-hammered into a sheet, then cut with a chisel, and rolled to form the bead. If the native copper has been melted and then cast, however, there is no way of distinguishing it with certainty from copper smelted from its ore.

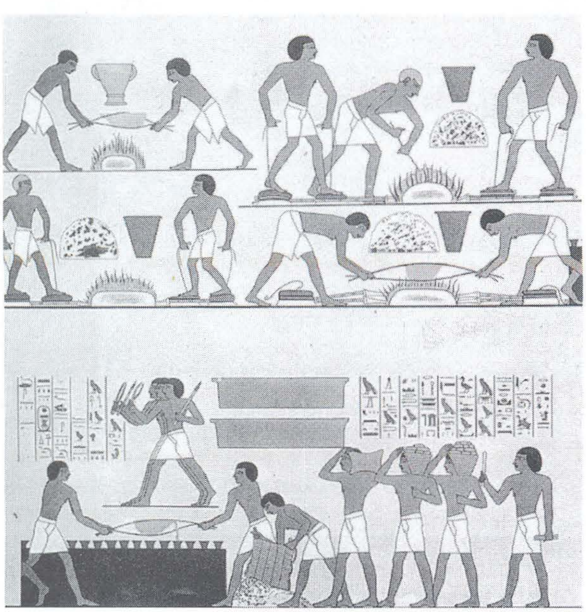
Alloying

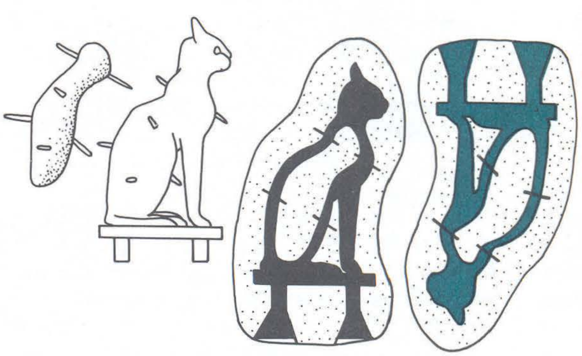
The alloying of copper with arsenic or tin represents a great step forward in metallurgical practice. Alloying can have a number of beneficial effects. In the first place arsenical-bronze or tin-bronze are both harder and less brittle than copper. Mainly for this reason the metal blades of weapons – daggers and spears – are generally of bronze, and such weapons that were made of copper were probably of very little use in practice. Certainly the early swords of the Near East and of Europe are of bronze: copper swords would simply be too fragile to be functional.

The addition of arsenic or of tin can also facilitate manufacture in several ways. They can be useful in the casting process by avoiding the formation of bubbles or blow-holes in the copper, and they improve the workability of the object by allowing repeated hammering (with or without heating) without the object becoming brittle. The ideal proportion of tin to copper in tin-bronze is about 1 part in 10.

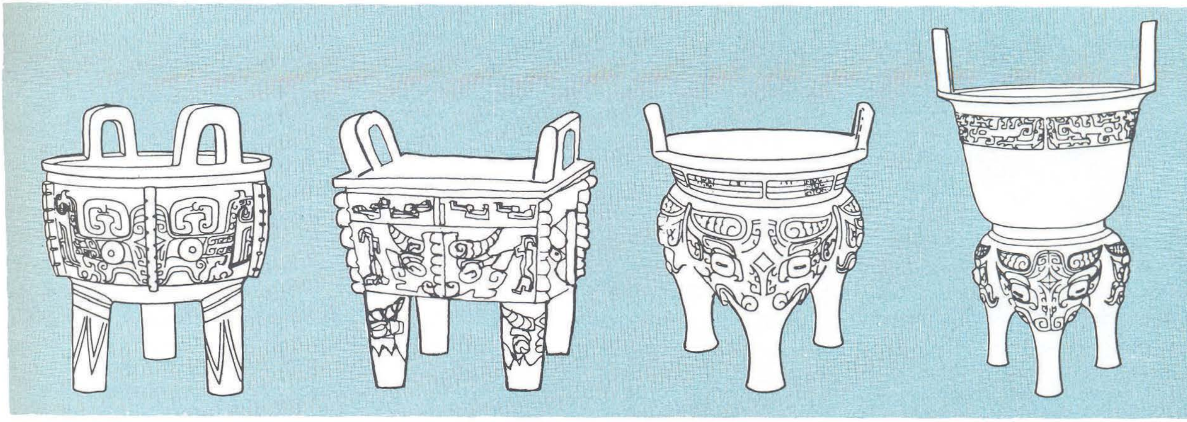
Naturally the presence of tin or arsenic is an indication that alloying may have taken place. But in the case of arsenic it is probable that arsenic-rich copper ore was used in the first place, and that the arsenic is not a deliberate additive, so that favorable results owed more to luck than to judgment. There is no way of being certain for a single artifact in isolation. But analysis of a series of artifacts can reveal a consistent pattern indicating careful control and hence probably intentional alloying. For example, when applied to Bronze Age material from the Near East by E.R. Eaton and Hugh McKerrell, X-ray fluorescence showed an extensive use of arsenic minerals in the alloys, probably to provide a silver-colored coating on the copper. Indeed, they found that arsenical copper accounts for about one-quarter to one-third of all metal from Mesopotamia over the period 3000 BC to 1600 BC, making it two or three times more important than tin-bronze at that time.

The composition of gold and silver alloys can be deduced by determining their specific gravity. In this way, it has been found that Byzantine coins were debased to a lower silver value between AD 1118 and 1203. An examination of cross-sections of the coins also enabled M.F. Hendy and J.A. Charles to ascertain the method of manufacture, because the microstructure indicated that the coin blanks were cut from sheets (either cold- or hot-worked), rather than stamped from cast droplets.





Casting. (Above) The lost-wax method. In this Egyptian example (c. 1500 BC), a clay core is made and then a wax model built around it. The model is encased in a clay mold which is subsequently baked, allowing the melted wax to be poured off. Molten metal is poured into the now hollow mold (colored in the diagram), and finally the clay is broken away to reveal the metal casting. (Left) An Egyptian tomb painting of c. 1500 BC shows foundrymen casting bronze doors. After heating using foot bellows (scene above), the molten metal is poured into a large clay mold (scene below).



In China, the casting of metal objects in ceramic piece-molds was perfected during the Shang dynasty, c. 1500 BC. In contrast with the technique used in the western Old World, most care went into shaping the mold rather than the model. Large numbers of molds were produced in workshops to supply the foundries. Masterpieces such as these bronze ritual vessels were the result.

Casting

Information on the type of mold used can generally be obtained by the simple inspection of the artifact. If it shows evidence of casting on both upper and lower surfaces, a two-piece mold was presumably used. More elaborate shapes are likely to have required the lost-wax (*cire perdue*) technique which reached a high degree of perfection in the New World (see also Chapter 10). This ingenious and widespread technique involves modeling the desired shape in wax, and then encasing the model in fine clay, but leaving a small channel to the exterior. When the clay is heated, the melted wax can be poured out; thus the clay becomes a hollow mold, and molten metal can be poured into it. After the clay casting is broken away, one is left with a metal copy of the original model. This is, of course, a "one-off" method.

There are several ways in which the technique can be detected in the archaeological record, quite apart from the scanty accounts and illustrations left, for the New World, by Spanish colonists, who mention gold (though not copper) being cast in this way. Apart from surviving molds (see below), evidence exists in the form of black fragments of clay casing which still adhere to a few metal figures. Experiments, sometimes carried out with original unbroken molds, have shown the effectiveness of the lost-wax method.

The examination of sections by metallurgical microscopy (see box p. 341) and electron probe microanalysis can also yield more detailed data on manufacture. The British metallurgist J.A. Charles studied some early copper axes from southeast Europe, and found a great increase in oxygen content toward the upper flat surface: the copper oxide content was 0.15 percent at the lower surface, but 0.4 percent at the upper. This was a clear indication that these Copper Age axes were cast in an open mold.

It should be noted, however, that hammering and annealing can produce results similar to casting. It does not follow that a ribbed dagger was cast in a two-piece mold just because it has a rib on both sides, for this effect can be achieved by hot-working. Metallographic analysis is needed to be sure about the production method.

Detailed evidence of the method of manufacture can be obtained when the by-products of the process are examined, and deductions can also be made from surface traces on some objects. Lumps of excess metal at the ends of figurines were usually removed by the craftsperson, but occasionally they remain attached and thus show in what position it was cast (normally head downward). Similarly unfinished are objects on which the casting seams or "flashes" – where a little metal ran into the join between two halves of a mold – have not been burnished away. On an incense burner from the Quimbaya region of central Colombia, made of a gold-rich alloy in the shape of a human face, one can see a vertical line on the forehead and chin, and a raised seam inside the hollow foot of the pedestal.

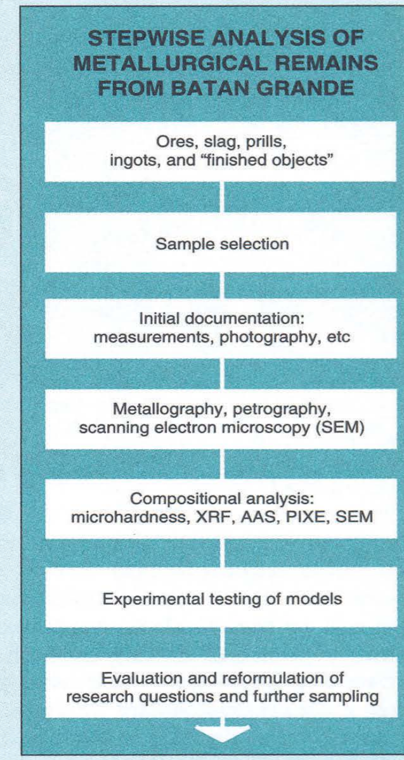
Molds can yield much useful information, and since they were often of stone they have frequently survived. Even the broken clay casings of the lost-wax method have occasionally been preserved. Two unbroken specimens have been found in an undated tomb at Pueblo Tapado, in the Quimbaya region of Colombia.

COPPER PRODUCTION IN PERU

At Batán Grande in the Central Andean foothills of northern coastal Peru, a team of archaeologists and allied specialists led by Izumi Shimada investigated various aspects of ancient copper alloy production. From 1980 to 1983 they excavated over 50 furnaces at three sites near rich prehistoric copper mines; they estimate there were hundreds more furnaces at these sites. This was copper alloy (copper and arsenic) smelting on an industrial scale, from about AD 900 to 1532 when the Spanish began their conquest of the Inca Empire. The sites provide ample field evidence that Central Andean metalworking was one of the major independent metallurgical traditions of the ancient world.

At one hillside site an entire smelting workshop was revealed, with furnaces, thick layers of crushed slag and charcoal, large grinding stones (*batanes*) up to a meter in diameter, and dozens of *tuyères* (ceramic blowtube tips), as well as food remains and some copper and arsenic-bearing ore. The furnaces, typically about 1 m apart, were in rows of three or four.

Replicative smelting experiments using a 600-year-old furnace and blowtubes have shown that



***Flowchart** to indicate how specialists in various fields, using different techniques, worked together to help understand the smelting process. (XRF, AAS, and PIXE are explained pp. 360–61)*

***Excavated furnaces** (left), aligned east-west and north-south, dating to about AD 1000.*

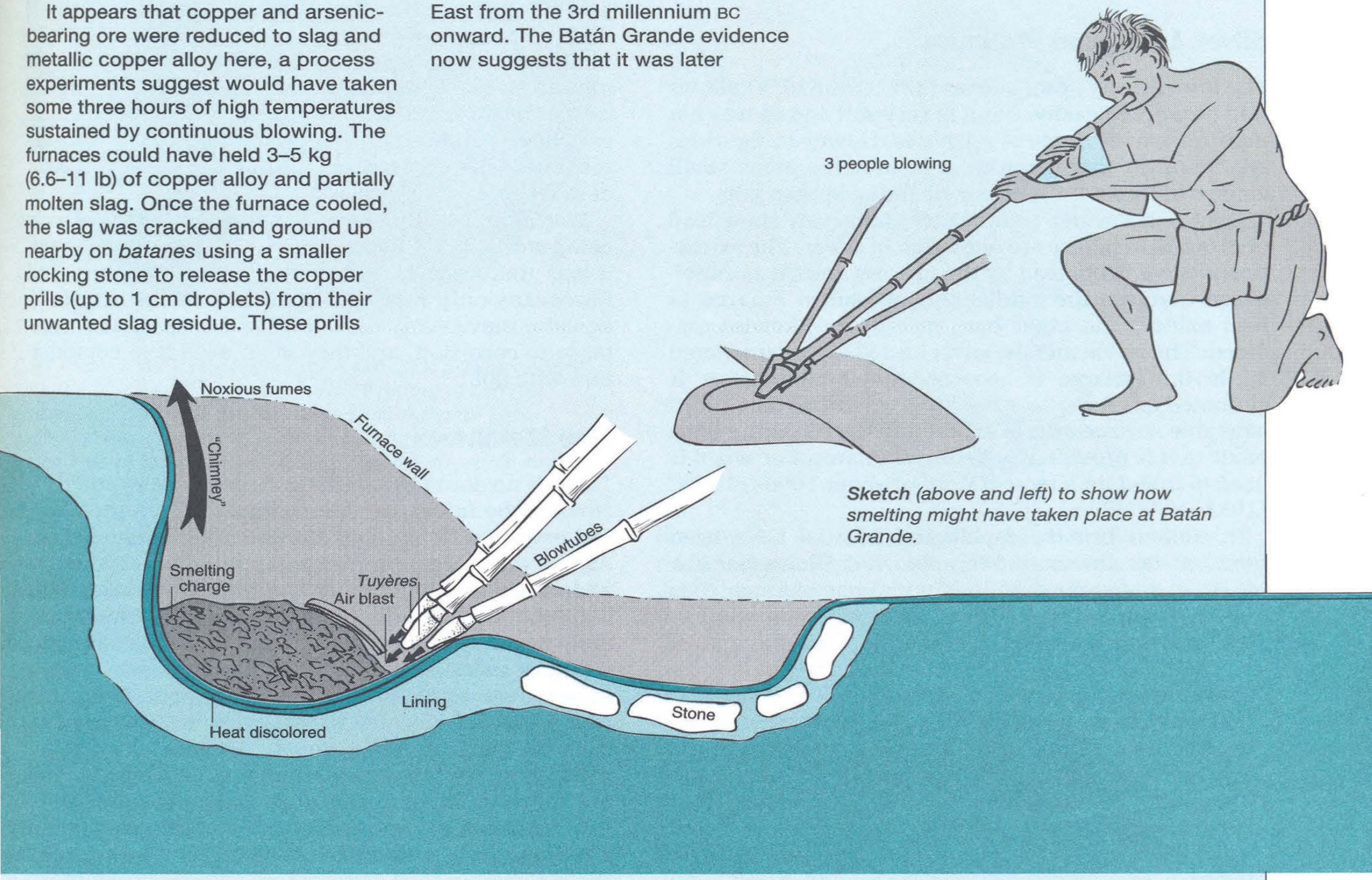
Being unbroken, it is clear they were never used, but both were intended for the casting of small ornaments. According to a study done by Karen Bruhns, the molds themselves are shaped like a flattened flask; they have a small hole pierced in the bottom to permit air to escape when the metal was introduced, and thus avoid formation of a bubble.

The study of *slags* can also be informative. Analysis is often necessary to distinguish slags derived from copper smelting from those produced in iron production. It is relevant as well to test for sulphur which is an indicator of sulphide ores. Crucible slags (from the casting process) may be distinguished from smelting slags by their higher concentration of copper.

The microchemical analysis of *residues* in pottery vessels (Chapter 7) has also produced evidence of metalworking. Rolf Rottländer's analysis of small pots from the Iron Age (Hallstatt) hillfort of the Heuneburg temperatures of 1100°C could be attained (the melting point of copper is 1083°C or 1981°F). Each furnace was lined with a specially prepared "mud" that gave a highly refractory, non-stick, smooth surface capable of withstanding numerous firings. Some furnaces had been relined up to three times.

It appears that copper and arsenic-bearing ore were reduced to slag and metallic copper alloy here, a process experiments suggest would have taken some three hours of high temperatures sustained by continuous blowing. The furnaces could have held 3–5 kg (6.6–11 lb) of copper alloy and partially molten slag. Once the furnace cooled, the slag was cracked and ground up nearby on *batanes* using a smaller rocking stone to release the copper prills (up to 1 cm droplets) from their unwanted slag residue. These prills were then picked out and remelted in crucibles into ingots. At another part of the site the resultant copper was annealed and forged using faceted stone hammers to produce sheet metal and implements. Prills and implements were all arsenical copper.

Prills extraction existed in the Near East from the 3rd millennium BC onward. The Batán Grande evidence now suggests that it was later independently invented in the New World. New World metallurgists, however, apparently never had the benefit of bellows, and human lung-power limited the size of furnace and amount of ore smelted at one time.



***Sketch** (above and left) to show how smelting might have taken place at Batán Grande.*

on the Upper Danube found that one had been used for melting down copper alloys, while another had traces of gold and two others traces of silver.

A fuller understanding of the technology must come from the thorough examination of the facilities at the ***place of manufacture***. Ingots, slag, and other by-products such as molds, fragments of crucibles often with slag inside, broken *tuyères* (the nozzles of pipes for conducting air), failed castings, and scrap metal in general all provide clues to metallurgical methods. For example, ingots of copper often solidified at the bottom of smelting-furnaces, and their shape thus reveals the shape of the structure's base. One bronze-foundry site, at Hou-Ma, Shaanxi Province, China, dating to 500 BC, has yielded over 30,000 items including piece-molds, clay models, and cores. The Chinese perfected the system of piece-molding quite early on, already at the time of the Shang dynasty around 1500 BC. As with most of the finest early bronze-working, the principle was that of lost-wax casting. Extraordinary works of craftsmanship were produced by the Chinese in this way.

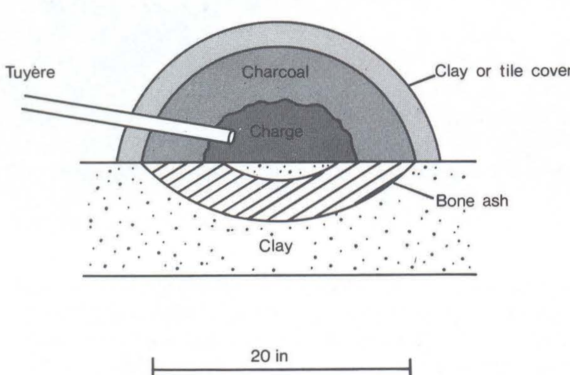
Remains of furnaces, as for instance found at the Peruvian site of Batán Grande, can provide a whole range of information about the technology of the manufacturing process (see box, pp. 344–45).

Silver, Lead, and Platinum

The low melting point of ***lead*** (327°C or 620°F) allows it to be worked easily, but it is very soft and so was not used for a wide range of purposes. However, figurines are found in this material, and in some areas small clamps of lead were used for mending broken pots.

Lead has a wider significance, however, since lead ores found in nature are often rich in ***silver***. The extraction of silver from lead by the process known as cupellation involves the oxidization of lead to litharge (a lead oxide), and other base metals are likewise oxidized. The noble metals, silver and gold, are unaltered while the litharge is absorbed by the hearth or is skimmed off. A shallow hearth is needed so that a considerable surface area is exposed to the oxidizing blast of air that is provided by bellows. Charcoal or wood is used to maintain a temperature of about 1000–1100°C (1832–2072°F).

In Roman Britain, cupellation hearths have been found at the towns of Wroxeter and Silchester. The hearth at Silchester was lined with bone-ash, which is



Reconstruction of a cupellation hearth found in the Romano-British town of Silchester. The hearth was probably used to extract silver from coins of debased silver and copper content.

porous and absorbent. Analysis of this hearth suggested that it had been used for the cupellation of copper, since it contained globules which were 78 percent copper. It is likely that it was used to extract silver from coins of very debased silver, with a large copper content.

Slag found in huge quantities (16–20 million tons) at the 8th/7th century BC site in Rio Tinto, Spain, proved on analysis to be primarily from silver metallurgy: the ore seems to have been very rich (600 g per metric ton), but very few metal objects have been found. The distribution of slag and drops of lead in many houses rather than in large piles suggested to the excavators, Antonio Blanco and J.M. Luzón, that the metalworking occurred as a domestic activity instead of in factories.

Platinum (melting point 1800°C or 3277°F) was being worked in Ecuador in the 2nd century BC, though it was unknown in Europe till the 16th century and Europeans only managed to melt it in the 1870s. In Ecuador they clearly liked it for its hardness and resistance to corrosion, and they often used it in combination with gold.

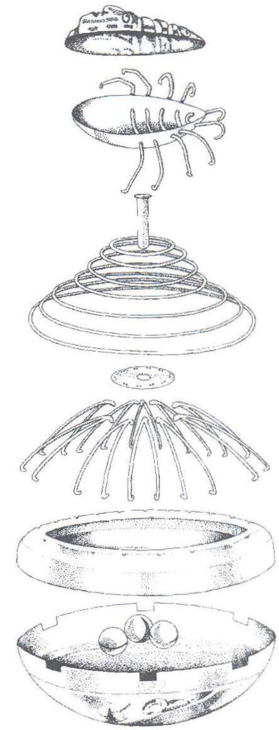
Fine Metalwork

There is no doubt that early craftspeople very soon discovered the full range of techniques which their control over pyrotechnology allowed. By the late Bronze Age of the Aegean, for example, around 1500 BC, as wide a range of techniques was available for working with non-ferrous metals as was used in the Classical or early medieval periods. For instance, the techniques of working sheet metal were well understood, as were those of stamping, engraving, and repoussé working (work in relief executed with hand-controlled punches from the back of sheet metal). Filigree work (open work using wires and soldering) was developed by the 3rd millennium BC in the Near East, and granulation (the soldering of grains of metal to a background usually of the same metal) was used to achieve remarkable effects, notably by the Etruscans.

Astonishing collections of fine metalwork, displaying great skill, have been excavated in recent years at the sites of Sipán and Sicán in Peru. The three royal tombs found at Sipán belong to the Moche period, and probably date to between the 1st and 3rd centuries AD. The Moche metalworkers were accomplished in a variety of techniques (see illustrations opposite).

In general, the method of manufacture can be established in such cases by careful examination, without more sophisticated analysis.

Most of these traditional techniques of manufacture



Gold spider bead – one of 10 that made up a necklace found with the "Old Lord" of Sipán, possibly dating to the 1st century AD. *The bead was made up from different parts (right), using a variety of techniques. The three gold spheres in the base of the bead would rattle when the wearer moved.*

may still be seen in use in towns of North Africa and in the bazaars of the Near East. There is usually much more to be learnt from careful study of the work of a skilled craftsperson operating with a traditional technology than there is from some less adept attempt at experimental archaeology undertaken by an experimenter who does not have the benefit of generations of experience.

Plating

Plating is a method of bonding metals together, for instance silver with copper, or gold with copper. The ancient Peruvians can be shown to have used methods of electrochemical plating of precious metals once thought to have been invented in late medieval or Renaissance Europe, where iron and steel armor was plated in gold.

Heather Lechtman and her colleagues undertook an analysis of some gold-plated objects of hammered sheet copper from a looted cemetery at Loma Negra, Peru. These dated to the first few centuries AD, the early Moche period, and included human figures, masks, and ear ornaments. Some had very thin gold surfaces that had not been attached mechanically to the copper. In fact the gold was so thin (0.5 to 2 micrometers) that it could not be seen in cross-section under a microscope at 500× magnification; but its thickness was very even, and it covered the edges of the metal sheets. This was clearly not a simple application of gold leaf or foil.

A zone of fusion between gold and copper indicated that heat had been applied to bind them together. It could not be modern electroplating, which uses an electric current, but its results were similar. Therefore the investigators looked at the possibility of electroplating by chemical replacement. In their experiments they used only chemicals available to the ancient Peruvians, and processes that did not require any external electrical current. They used aqueous solutions of corrosive salts and minerals (common in the deserts of the Peruvian coast and thus available to the Moche) to dissolve and then deposit the gold, and found that it spreads onto clean copper sheeting that is dipped into the solution, if boiling occurs for five minutes during immersion. To achieve a stable bonding, it is necessary to heat the plated sheet for a few seconds at 650–800°C (1202–1472°F). The results were so close to the Loma Negra artifacts that this method – or one very similar – was probably that used by the Moche.

EARLY STEELMAKING: AN ETHNOARCHAEOLOGICAL EXPERIMENT

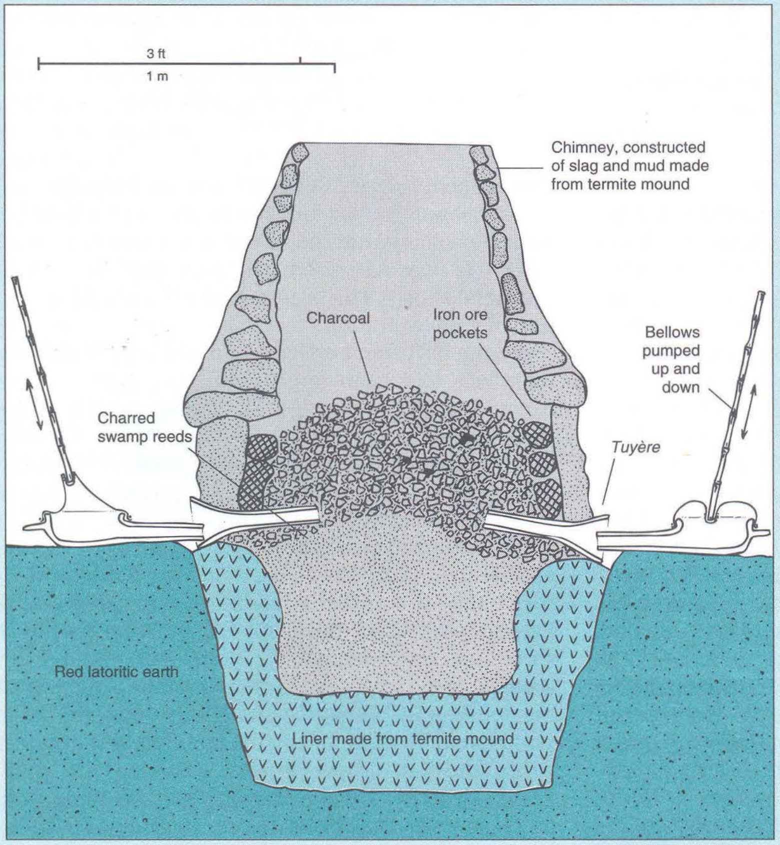
Ethnoarchaeological projects that involve detailed observations about manufacturing processes are usually associated with the making of stone tools and ceramics, or with weaving; yet much has also been learned about metalworking by a number of investigators.

One such project, combining ethnography with archaeology and experiment, was carried out in northwest Tanzania by Peter Schmidt and Donald Avery who worked among the Haya, a Bantu-speaking agricultural people living in densely populated villages on the western shore of Lake Victoria. The Haya now use cheap European tools, but had oral traditions concerning their own ancient steelmaking process, which had been used as recently as 60 or 70 years ago. They still have an active blacksmithing tradition, in which scrap iron is employed. Some older men, a few of them smiths, remembered the traditional way in which iron had been smelted, and they were more than willing to recreate the experience.

The Haya were therefore easily persuaded to construct a traditional furnace, which was 1.4 m (4 ft 6½ in) high, cone-shaped, and made of slag and mud, built over a pit, 50 cm (20 in) deep, lined with mud and packed with partially burned swamp grass. These charred reeds provided carbon that combined with molten iron ore to produce steel. Eight ceramic blow tubes (*tuyères*) extended into the furnace chamber near its base, each one connected to a goatskin bellows outside. These tubes forced preheated air (up to 600°C or 1112°F) into the furnace, which was fueled by charcoal. With this apparatus the Haya could achieve temperatures between 1300° and 1400°C (2372–2552°F), high enough to produce carbon steel.

Archaeological verification of the Haya's claims came from excavations on the lakeshore which uncovered remains of 13 furnaces almost identical to the one built by the modern people. Radiocarbon dates obtained from charcoal showed that they were 1500 to 2000 years old. Iron slag was also found which had a flow temperature of 1350–1400°C (2462–2552°F). Furnaces of similar date have since been found elsewhere in the same region of East Africa.

In short, the Haya had the technology to make medium-carbon steel in preheated forced-draft furnaces some 19 centuries before Europe developed the same capabilities.



***Idealized profile** of a Haya iron smelting furnace, before the addition of the mixed iron ore and charcoal charge. Bellows that were pumped up and down with a stick forced air through* tuyères *(clay pipes) deep into the center of the furnace.*

Iron and Steel

Iron was not used in the New World during pre-Columbian times, and makes its appearance in quantity in the Old World with the inception in the Near East of the Iron Age around 1000 BC. There is evidence, however, that it was worked rather earlier, notably in Hittite Anatolia. Meteoric iron (iron deriving from meteorites, and found naturally in the metallic state) was widely known in the Near East, and cylinder seals and other ornaments are made from it. But there is no evidence that it was extensively worked.

Once the technique of ***smelting iron*** was well understood, it became very important, not least in Africa, since iron is more widely found in nature than is copper. But it is much more difficult to reduce – i.e. to separate from oxygen with which it is found combined in nature in the form of iron oxides. It requires much more strongly reducing conditions.

Iron may be reduced from pure iron oxide at about 800°C (1472°F) below its melting point of 1540°C (2804°F). But in practice the iron ores also contain other unwanted minerals, called gangue, in addition to the oxides. These must be removed in the smelting process by slagging, where a sufficiently high temperature is reached for the slag to become liquid and to drain away, leaving the iron in a solid state as a sponge or "raw bloom."

The simplest and easiest furnaces for iron smelting were bowl furnaces – hollows in the ground lined with baked clay or bricks. The ore and charcoal were placed in the bowl furnace and the temperature brought up to around 1100°C (2012°F) by the use of bellows.

The next stage is the hot working of the iron by forging, which takes place above ground in the smithy or forge. It is not always easy to distinguish between smelting sites and smithing sites, although if ore is found along with slag, that usually indicates smelting.

The production of ***cast iron*** requires a sophistication in the construction and operation of furnaces which did not become widespread in Europe until well into the Christian era, more than a thousand years after the production of ***wrought iron*** (although small statuettes of cast iron appear in Greece as early as the 6th century BC). In China, however, cast iron and wrought iron appear almost together in the 6th century BC, and cast iron was regularly used for making useful tools in China long before it was in the West. Cast iron is a brittle alloy of iron which has a carbon content between 1.5 percent and 5 percent. Its relatively low melting point (around 1150°C or 2102°F), which is lower than that of steel or of wrought iron, allows it to be cast in the molten state. The emphasis in early China is thus upon cast iron rather than wrought iron: in this respect metallurgy in the Far East and in Europe followed very different paths.

Steel is simply iron that contains between about 0.3 and 1.2 percent carbon, and it is both malleable and capable of hardening by cooling. True steel was not produced until Roman times, but a rather similar although less uniform product was made earlier by the process of carburizing (see box opposite): this was achieved by high temperature heating of the iron in contact with carbon. Initially it may have taken place by accident, while the iron was heated in contact with red-hot charcoal by the smith in the process of forging.

The extent to which iron has been carburized, and the processes used, are best assessed by metallographic examination of the artifact in question.

Some apparently featureless lumps of metal may be more than they seem. Corrosion products can "grow" out of an iron object to mineralize and even encase any associated wood. The resulting metal lump may contain a void in the exact shape of an object that has corroded out. X-rays can reveal the hidden shape inside, and, as with the bodies from Pompeii or endocasts of brains (Chapter 11), a cast can be made and extracted.

SUMMARY

In this chapter we have highlighted some basic questions about early technology, and considered how to find answers to them. The examples presented demonstrate the mass of varied technological information that the archaeologist can extract by a combination of excavation, laboratory analysis, ethnographic information, and insight from experimentation. It could even be said that without experiments our knowledge of ancient technology would be minimal.

Ethnography and archaeological context may suggest the function of a stone tool; but only analysis of its microwear can demonstrate its likely use. Microwear studies themselves depend on experiments for categories of wear and to give them meaning. Nevertheless, ethnoarchaeology is proving extremely valuable. Observation of craftspeople in other living cultures by archaeologists who know what kind of information they require has probably arrived just in time, before the final vestiges of many of the ancient processes and traditions die away. No observation made in the present can definitively prove anything for certain about the past. But archaeology deals in degrees of probability, and a hypothesis which has been based on solid evidence from excavation, analysis, ethnography, and experiment is about as close to truth as we can come.

FURTHER READING

There are no up-to-date general accounts that cover all the methods discussed in this chapter. Broad surveys of ancient technology include:

Forbes, R.J. (series) *Studies in Ancient Technology*. E.J. Brill: Leiden.

Hodges, H. 1964. *Artifacts: an Introduction to Early Materials and Technology*. John Baker: London.

Hodges, H. 1971. *Technology in the Ancient World*. Penguin Books: Harmondsworth & Baltimore.

James, P. & Thorpe, N. 1995. *Ancient Inventions*. Ballantine Books: New York; Michael O'Mara: London.

Lambert, J.B. 1997. *Traces of the Past: Unraveling the Secrets of Archaeology through Chemistry*. Helix Books/Addison-Wesley Longman: Reading, Mass.

Rosenfeld, A. 1965. *The Inorganic Raw Materials of Antiquity*. Weidenfeld & Nicolson: London.

White, K.D. 1984. *Greek and Roman Technology*. Thames & Hudson: London; Cornell University Press: Ithaca, NY.

Other important sources are:

Anderson, A. 1984. *Interpreting Pottery*. Batsford: London; Universe: New York 1985.

Coles, J.M. 1979. *Experimental Archaeology*. Academic Press: London & New York.

Keeley, L.H. 1980. *Experimental Determination of Stone Tool Uses*. University of Chicago Press: Chicago.

MacGregor, A. 1985. *Bone, Antler, Ivory, and Horn Technology*. Croom Helm: London.

Orton, C., Tyers, P., & Vince, A. 1993. *Pottery in Archaeology*. Cambridge University Press: Cambridge & New York.

Rice, P.M. 1987. *Pottery Analysis: a Sourcebook*. Chicago University Press: Chicago.

Shepard, A.O. 1985. *Ceramics for the Archaeologist*. Carnegie Institute: Washington, D.C.

Tait, H. (ed.) 1991. *Five Thousand Years of Glass*. British Museum Press: London.

Tite, M.S. 1972. *Methods of Physical Examination in Archaeology*. Seminar Press: London & New York.

Tylecote, R.F. 1987. *The Early History of Metallurgy in Europe*. Longman: London & White Plains, NY.