

Section four | Regularity

Regularity in the development of the basic tools of the Stone Age

THE results set out above in the study of ancient tools permit some general conclusions to be drawn about the regularity in their development, that is an attempt to work out the fundamental tendencies, as it were, observable in the evolution of tools during the early stages of the history of society.

This is due to the fact that all tools, including the most ancient, are a means of acting upon objects of the external environment with the intention of altering them in a way necessary for man. In concrete terms the fundamental processes of work carried out with tools are directed towards the alteration of the external form or physical consistency of an object taken in its natural state, be it stone, earth, wood, bone, animal or vegetable, principally by dividing the whole into parts, separating one or many particles from the whole or reducing the whole to small parts. These alterations are achieved by cutting, chopping, splitting, scraping, boring, grinding and so on.

In correspondence with such tasks, and in so far as their completion derives from a preconceived plan, the main tendencies in the development of tools have been directed towards reduction in the resistance of the materials of which objects in the external world are made, raising the productivity of work, and trying to bring within the cognizance of society all new natural materials. The following basic tendencies can be discerned in the evolution of tools.

Firstly, to improve the manufacturing processes in which the tools were used prehistoric man changed them by reducing the edge angle of their working part. This applies to all kinds of tools with blades or points intended to penetrate into a plastic material like meat, skin, wood, earth and so on.

Secondly, man changed the same category of tools by giving them a smoother and more even surface on the working part contiguous to the tip or blade, in order to reduce friction against the worked material.

Thirdly, man improved his tools, especially striking ones, by raising the force of physical action on the object of work, or in other words he increased their mechanical power.

Fourthly, he worked out methods of increasing the

rapidity of movement of the tool during the working process.

Fifthly, he expanded manufacture by differentiation of function and specialization, creating tools of new shapes, dimensions, and material.

Obviously these five tendencies in the development of tools do not exhaust all aspects and directions taken by the alterations and improvements. Yet it can be clearly seen that these five are the fundamental directions of change characteristic of the early stages of development. In later periods the number grows, as for example the subsequent acquisition by man, with the progress of technology, of means of raising the resilience and toughness of the tools themselves by altering the physico-chemical properties of the material of which they were made. However, this tendency only assumes exceptional importance with the adoption of metals, and as far as stone tools are concerned man from the beginning was employing a material not susceptible to internal change. Only with the so-called insertion technique in which stone and bone were united did man achieve some success in raising the potentiality of the material. It is true, of course, that we have in this only a mechanical combination of two qualitatively different materials, leading to a mutual reduction of their weaker sides without any alterations of the properties of the materials themselves.

It should be noted that, in order to enhance the practical use of natural matter, men in very early times began to try to change the physico-chemical properties of necessary objects by employing the action of fire, sun, and water. The first and most important achievement in this field was the cooking of animal and vegetable food with the help of fire; roasting and baking arose at the same time as fire was mastered. Besides cooking man very early tried to use fire for working his tools in wood and bone. Charring of wooden points in boar spears, clubs, and javelins, in order to increase their toughness and hardness, took place already in palaeolithic times. Then followed steaming and soaking of bone and antler to soften them and make working easier. The hardening of arrows by heat was rather later. However, problems of the use of physico-chemical methods of work (fire,

water, sun) fall outside the scope of this book, which is concerned only with mechanical tools and mainly with stone ones.

Crucially significant in the development of ancient tools were not only the reduction of friction by making smooth (sliding) surfaces, but also the opposite tendency to increase the friction on tools designed for working hard materials (abrasives) or trituration of colouring and food matter (pestles, colour-mortars, and querns).

The category of abrasive tools received a definite extension in the later stages of development of prehistoric technology. In palaeolithic and neolithic times man employed as abrasives (pestles, colour-mortars, querns and various grinding tools) granite boulders, pebbles, and plaques, which retain traces of work but have not themselves undergone working (shaping and cutting out of the working surface). However, during neolithic times a tendency is already noticeable towards a significant alteration of the natural shape of abrasive stones (sandstones or crystalline rocks) for a more effective use of the mechanical properties of the granular rock. Gradually man enlarged the working areas (the friction surfaces) on pestles, colour-mortars, and plaques, which on whetstones and grinding tools took on a shape corresponding to that of the worked object, giving higher efficiency in terms of time and quality of work. An excellent example of such an accomplished abrasive is the grinding tools from Verkholsk.

Another phenomenon that is noteworthy in the development of stone tools again was intended not to reduce friction but on the contrary to increase it. This is the perfection of a tool with toothed or saw-like edge made by bifacial retouch. Such tools were spear- and arrowheads, knives for dismembering animal carcasses, gutting fish and cutting meat, flint sickles and saws. All these were designed for use on elastic and fibrous matter; the teeth bit into the fibres and tore them apart. However, to some degree this tendency ran contrary to that mentioned of reducing the edge angle of the blade. For example meat knives with very thin blades easily cut animal fibre, but at the same time they were very brittle.

The development of tools with a toothed blade received new possibilities at a relatively late stage with the adoption of metals, when first bronze and then iron saws for use on bone came into use, and finally wood-working saws.

Very close to the line of development leading to a decrease¹ of the resistance of the material is the burin, in essence a one-toothed saw for working bone, which appeared in upper palaeolithic times. In neolithic times

it fell behind by comparison with chopping tools (axe, adze), but after the appearance of metals the role of the burin gradually became more important and it took on major significance as a result of the development of mechanical working of bone, wood, stone, and metals.

It is necessary to draw attention to the tendency towards an increasing economy in the use of material with the aim of reducing dependency on it because of the difficulty of obtaining it. Some archaeologists have noticed this.² In the present work attention is mainly devoted to the tendencies in the evolution of prehistoric technology which were most important for mechanical tools of the Stone Age, and which can serve as objective principles for assessing the development of ancient tools. For the sake of brevity we will call the first tendency reduction in the angle of sharpness; the second, reduction of friction; the third, increase in the force applied; the fourth, increase in rapidity of movement; the fifth, specialization; and the sixth, economy of material.

With regard to lower and middle palaeolithic tools (Chellean, Acheulian, and Mousterian) there is not much to say, as the functions of the tools have not been studied. Nevertheless some general characteristic can be discerned. The angle of sharpness of these tools is very great, but some diminution is detectable between Acheulian and Mousterian tools. The amount of friction in use (cutting or whittling), particularly with tools made by bifacial percussion, was great because the working edge of such tools was formed by large uneven conchoidal scars. Hand-axes of Chellean type could be used in that kind of mechanical work which made use of their weight, that is striking actions. Such would be hewing bone, breaking rotten wood to get insects, making nests in hollow trees and in the ground, cutting off knots and young branches for wooden tools (staves, clubs, boar spears) and so on.

The reduction of the angle of sharpness in the blade in Acheulian hand-axes as against Chellean ones is quite obvious.³ In the latter it is 70–75°, in the former 30–50°, while the angle of the point in profile is 70–90° and 30–90°, and the facet angle 75–95° and 30–50°, in the two cases.

The blades changed in shape, retouch smoothing them out and getting rid of the zigzag. This change took place in the blade and point because in all types of plastic work on wood and bone the Chellean kind of implement is unsuitable, like all tools with a wavy edge. They would not have been practical as side or end-scrapers and would never have been used for cutting up carcasses, cutting fibrous plants and so on. The greater part of

¹ Russian text has 'increase', T.

² G. A. Bonch-Osmolovsky, *Chelovek*, 2–4 (1928), p. 182.

³ F. Bordes and P. Fitte, *L'Anthropologie*, 57 (1954), pp. 1–44, pl. I–IV.

these functions was probably carried out with flakes, which accompany hand-axes in abundant numbers and varied forms on Acheulian sites.

An extensive use of flakes and a permanent demand for them called into being the so-called Mousterian technique, that is the technique of flaking such flat rough-outs off a pyramidal core. The leaf-shaped flakes so produced, of course, required finishing work, but as tools they were distinguished by great possibilities, including a reduction in the angle of sharpness of point and blade. They could be retouched on one face, from ventral on to the dorsal side, which would reduce friction in working bone or wood. There were no facets on the slightly convex but smooth ventral face.

It was precisely in the Mousterian period that a more accomplished method of thin pressure retouch was adopted, well known from points, scrapers, and bone retouchers of this period. Fine pressure retouch made it possible to strengthen the relatively weak edge angle, and also to sharpen the tip.

An economy in material is noticeable with the appearance of the core. Repeated flaking of leaf-shaped flakes from a core made it possible to get a considerable number of rough-outs from a single flint nodule.

The birth of the Mousterian technique was not accidental; a technique of flaking off rough-outs from a core developed gradually and side by side with bifacial working. If on the one hand the prototype of manufacture was the flaking of a pebble or nodule leading to the Clactonian, Levallois, and Mousterian forms of tool, mainly used as knives and scrapers; then on the other an initial stage is represented by the rough sharpening of a pebble at one end, subsequently converted into bifacial working. In both cases a striking technique (percussion) was employed.

As regards a growth in productivity and specialization of the tools we still have little analytical evidence for firm judgment. Preliminary study of material from the caves of Kiik-Koba and Kosh-Koba and from the site at Volgograd makes it reasonable to consider that in Mousterian times man already had several types of tool at his disposal. Of course, the real existence cannot be accepted of such tools as bolas, 'disks' used as axes, 'choppers' and other conventionally named tools, classified by western archaeologists not by their purpose but by their shape. Obviously Mousterian industries contain stone strikers, stone and bone retouchers, bone rests or anvils, pointed flint knives for cutting up carcasses, knives made on flakes for cutting meat and whittling wood or bone, side scrapers for working skin, perforators, bone and stone heads for boar spears and other tools, not to mention wooden clubs, boar spears, devices for making fire and so on.

From the point of view of increasing the force and speed of movement of tools, no important achievements

are recognizable in middle palaeolithic techniques. That the physical potential of Neanderthals was used irrationally can be judged by the fact that all the stone tools were held in the hand without separate handles. This explains the strong development of the width of phalanges (particularly the ungual phalange), as we can see by the skeletal remains from Kiik-Koba, Krapina, La Ferrassie and other sites.

Javelin-throwing, which requires a high degree of flexibility of the spine and free movement of the shoulder joints, was probably unknown to Neanderthals, and at all events cannot be proved. We can only speak confidently of the use of a non-throwing spear (the boar spear). European palaeolithic sites have yielded evidence of boar spears: Clacton-on-Sea, La Quina, Castillo and so on.

Very often lower palaeolithic and Mousterian man must have made use of the kinetic force stored up in the weight of stone, wooden and bone tools (choppers, clubs, antlers and so on). Strong muscular development is testified by the prominence of the projections on the bones to which the sinews were attached.

The change to the upper palaeolithic is marked by great achievements in all aspects of development in tools. Especially noteworthy is the new technique of making tools based on flaking off blades from a prismatic core, which made it possible to overcome several difficulties simultaneously.

Firstly, the angle of sharpness of the blade-edge of all categories of cutting tools was sharply reduced thanks to the flat section of prismatic blades; it now fell to below 20°. In addition greater opportunities revealed themselves for making every type of pointed tool (points, awls, perforators, drills), penetrating plastic materials with more facility because of the elongated shape of the blade.

Secondly, each blade consisted of a ready-made two-edged tool, whose sharp edges required blunting rather than sharpening. This led to the general development of two types of dulling retouch: fine (on the edge) and steep retouch in depth.

Thirdly, the prismatic blade allowed the creation of a new tool, the burin, thereby bringing into extensive daily use bone, ivory and antler, materials with high technical merits.

Fourthly, a significant economy in material was achieved by contrast with the preceding period, thanks to the new technique of blade-making, which to some extent eased man's dependence on the material. A person using a small quantity of flint could now achieve a significantly greater result.

Two difficulties arose with the new technique which man overcame with advantage to himself. One of these was that narrow two-edged tools were very often impossible to hold in the hand; they required handles, whose

appearance in this period represents an immense technical conquest.

The second difficulty was that prismatic blades are bow-shaped in profile, a feature that impeded their employment for daggers, heads for javelins, darts and other tools with a straight axis. A solution was found by the application of flat pressure retouch (Solutrean retouch), which permitted the removal of fine slivers from the blade in order to get straight but slightly shortened heads and knives.

Thus bifacial working was re-created in upper palaeolithic times, but now on a much higher technical basis. This bifacial pressure retouch was especially valuable when good nodular flint was lacking and man was obliged to use low-grade varieties, like the tabular material which we met in the lower layers of Kostenki I.

As regards reduction of friction of the tool against the worked material here also were obvious improvements. The reduction of the angle of sharpness of blade-edge and point thereby implied some reduction of friction, but the main achievement of the period was not in this way. The technique of blade-making was such that the blade produced was, as it were, ground smooth automatically; the flat belly and the three facets of the back had level and smooth surfaces. These and particularly the belly were already slippery and as a result reduced the resistance of the material as the tool encountered it.

Man systematically and persistently sought out more rational ways of working and reducing friction, even if he did it mainly by trial and error in the course of the work. Traces of wear show that blades used as knives for whittling wood and bone were grasped in the hand in such a way that the belly and not the back of the blade faced the material. Exceptions to this rule have hardly ever been detected. Blades of whittling knives are hardly ever retouched to ease friction, and, when they are, as a rule it is from the ventral side on to the back, not vice versa.

The increase in manufacture and specialization of tools in upper palaeolithic times became more evident. The requirements of a society of hunters in the periglacial zone of Europe and northern Asia made necessary new branches of manufacture, for which the previous range of tools was inadequate. Different operations earlier performed by one tool were now carried out with several. For example, there were meat and whittling knives each with its own shape and method of use, and besides this there were known: end-scrapers for dressing skin, burnishers, perforators and awls, bone needles, drills, burins, stone saws, side-scrapers for use on bone, chisels, axes, bone wedges, mattocks, pestles, mortars, pounding slabs, retouchers, pressers, spearheads,

harpoons, javelins, handles for various tools, and other tools.

Study of traces of use reveals that in upper palaeolithic times there was still no very sharp division of function between tools. Sometimes whittling knives were used for cutting meat, strikers as retouchers or pestles, and so on. Nevertheless division of function was one of the characteristic traits of the period; the properties of tools, for example flint blades, had become such that a mixing of functions in one tool was becoming more and more difficult. Whittling knives would require a blade either unretouched or barely trimmed from the ventral side, that is not toothed, but it was not essential for the blade to be straight; while on the other hand for meat knives straightness and a toothed edge were very important.

In upper palaeolithic times an increase in force of application of tools was achieved without any increase in human physical potential; indeed, it is possible that man then was physically weaker than Neandertal man. Nevertheless he was certainly higher in a social sense or in terms of technology.

Due to the use of the handles in which he mounted his knives and burins the application of useful energy was two to three times as great. This happened because a firmer grasp in the hand could make use of the muscular strength of the shoulder and upper arm to a much greater extent than when, as previously, a cutting tool had been used without a handle.

Handles on digging striking tools (mattocks) and chopping tools (axes) made it possible to increase significantly the coefficient of useful action of muscular energy, since the elongation of the handle made the movement more rapid. The increase in rapidity of movement was especially significant in projectiles, which were first adopted and brought into general use in upper palaeolithic times.

In the life of the most ancient periods of humanity hunting played an important part, but the advantage of humans over the animals they pursued was not great. It lay mainly in collective action, in the organization of drives of game, but once man was in a position to strike the animal from a distance by throwing a javelin his advantage was greatly increased. The sling, bolas and even the boomerang were not known everywhere, but javelin throwing became almost universal. It was precisely in this field that the principles were first realized of how to increase the rapidity of movement of objects over a distance.

The average flight of a light spear (dart) if we rely on the ethnographic evidence is 35–40 m; its average flight propelled from a spear-thrower¹ (woomera of the

¹ D. N. Anuchin, *Proceedings of the Fifth Session of Archaeologists at Tiflis* (Moscow, 1887), p. 333.

Australians) is 70–80m. This is a measure of the increase of distance obtained by palaeolithic man by means of increasing the rapidity of movement of his tools by a practical mastering of some elementary principles of ballistics.

Soon after the javelin, or perhaps at the same time, man explored the possibilities of more complicated ballistic devices by the creation of the sling, bolas and throwing club, whose flight is circular. The evidence as to whether these were employed in palaeolithic times is not known to us in a convincing form, but apparently they existed, although not everywhere.

Thus the most important technical advances in palaeolithic tools coincided with the cultural divisions in Europe: Chelles, Acheul, Moustier, Aurignac, and Solutré. The period known as mesolithic has been evaluated quite differently. This period in the evolution of the Stone Age has been regarded as an intervening stage without independent significance, merely serving as a link between two cycles of development, a sort of unconformity between geological layers. Not long ago some students still regarded the mesolithic period as one of decay and degeneration; study of technology of the period lends no weight to this view.

It cannot be merely chance that it is precisely in mesolithic times that man attempted in a considerable way to overcome one very weak side of stone tools that impeded further development in their use. This weakness consisted in the brittleness of stone and its inability to withstand pressure in movements and blows, and it was exacerbated by the fact that the angle of blade or point sharpness had been reduced, while at the same time the length of the working part had been increased.

In spite of all their other merits upper palaeolithic prismatic blades are very brittle rough-outs due to their narrow section. On sites of this period we encounter huge quantities of broken tools. Undoubtedly javelin and dart heads generally broke at the moment of impact against the animal's body; possibly many broke the first time they were used.

This feature is revealed by the broken shouldered points from Kostenki I and the leaf-shaped heads from Telmansk. On these sites a series of fragments have been found, not tips but stumps of the head. Evidently they had been brought home by the hunters with the shafts, but the tips of the heads would have been lost in the bodies of wounded animals.

The technique of insertion therefore was of immense significance. It was a new way of improving a tool to increase its toughness by uniting stone and bone in one construction.

The first steps in the manufacture of composite tools

were made at the end of upper palaeolithic times, but systematic and varied application of the new technique falls within the mesolithic period.

Flint inserts were mounted in grooves in bone rods without steaming, the bone evidently being just soaked. It is true that by the action of water bone swells only very slowly, but, owing to the lime in it, it dries quickly and grips.

The advantage of a composite tool lay mainly in the fact that it offered greater reliability in a blow or other cases where it was subjected to stress; if individual inserts broke or fell out they could be replaced. It gave weapons a longer life. Composite tools such as heads for spears, knives, daggers or harpoons could be made of variable length, which might exceed the length of prismatic blades.

They could be made absolutely straight without regard to the curvature of a complete blade. There was no need to resort to the laborious Solutrean pressure retouch, which required large cores or tabular flint.

The manufacture of so-called micro-blades once more reduced the angle of sharpness, reaching the thinness of a razor and left without retouch on the working edge. Only with a bone mount could a small thin brittle blade be brought into practical use.

Moreover, in this technique the principle of economy of such an important material as flint was carried to its practical limit, a circumstance with important consequences. A society possessing such a technique was no longer confined to the area of deposits of high-quality chalk flint. In any case many of the deposits of such flint had been destroyed at the end of the glacial period. For making inserts any material of the quartz family was suitable; pebble flint, agate, hornstone, chalcedony, and jasper, even if they occurred only in very small nodules. Flinty minerals, however, occur as pebbles (river, lake, and marine) in abundance almost everywhere.

All these merits of the insertion technique were so important that, after its appearance in mesolithic times, it continued into neolithic and even to some extent into early metallic times. An excellent example of composite tools in the neolithic period can be cited in the beautiful Siberian specimens from graves in Isakov, Serov, and Rasputin published by Okladnikov.¹

In the history of tools very great significance is attached to the invention of the bow, first brought into widespread use in mesolithic times. It became possible because man by experiment had reached the point where he grasped the value of the potential energy stored in elastic bodies, pre-eminently wood, with which he had had constant dealings. He had only to notice the strength of a bent branch or sapling.

¹ A. P. Okladnikov, *Materials and Researches on the Archaeology of the U.S.S.R.*, 18 (1950), pp. 183, 214, 365, 366.

Hunting society of mesolithic times because of the bow made a great advance in the increase of rapidity of movement of tools. The speed of an arrow exceeds by two and a half to three times that of a cast javelin, due to the brief impulse received from the bow string. The greater the speed the greater is the force and suddenness of the blow.

As regards distance of flight it was twice that of a javelin hurled from a spear-thrower, and three to four times that of one hurled from the hand. For example, the Veddah bow (Ceylon) tautened with the feet, according to the reports of K. G. Seligman and F. Sarasin, will shoot an arrow 300–350 m (free flight), which gives a practical wounding range of 150–200 m.

Yet the range of an arrow released from a bow and even its speed would have little practical importance without one essential feature of this hunting weapon, precision in back-sighting. Up to then not a single projectile (neither javelin, nor spear-thrower, nor sling, nor bolas, nor throwing club) had any kind of back-sight. The methods of throwing were learnt with great difficulty and were almost impossible to pass on by teaching. A bow allowed the arrow-shaft to be directed over open sights at the level of the hunter's eye, and so greatly simplified discharging missiles at game. On top of this the hunter could take a large supply of arrows with him because of their slight size and weight.

In order to appreciate the invention of the bow more fully it is necessary to remember that the principles of its mechanism were later employed very effectively in various types of cross-bows, which with traps and snares were the origin of ancient 'automatic' devices.

Ancient spear-, stone- and fire-throwing machines of Classical and early medieval times (cross-bows, catapults and so on) relied on the same physical mechanism, the elasticity of a piece of matter. Moreover, the technique of torsion is merely a specialized use of this physical property; the essential element here is a tightly twisted cord of ox sinews or woman's hair. The ballista, the Roman stone-throwing machine, is a typical specimen of torsion artillery.

Thus by the time all the possibilities within the principle of the bow had been exhausted society had practically entered into the fourth socio-economic stage, capitalism; the bow and cross-bow played some part in Europe even in the seventeenth century.

The cultural and technical achievements of the mesolithic period, besides the introduction of composite tools and bows and arrows, included also the invention of the adze and domestication of the dog. At this time and connected with great geological and climatic changes settlement began over new territories in all five continents. Finally it has to be noted that in mesolithic times agriculture started in the sub-tropical zone of the Mediterranean and tropical belt around the world.

A main feature of the development of neolithic tools which it is very important to notice is the fact that during this period society reached the limit to which the useful properties of stone, as the main technical material for tools, could be exploited.

With regard to the angle of sharpness no real advances can be discerned, but with regard to reduction of friction by means of grinding axes, adzes, chisels, and knives, there was an advance of the first magnitude. Attention must now be drawn to the fact that humanity in the Stone Age took a fresh step towards freeing itself from regional isolation by the perfection of its techniques of making its tools.

In neolithic times man began making axes and adzes by the technique of grinding, which, needless to say, can be regarded as a progressive achievement. Students concentrating on this, however, and noticing improvements in the working of wood have overlooked a consequence of this. In reality this narrow technical achievement opened a new era in the history of humanity. Vast tracts of the globe hitherto uninhabitable became accessible for settlement and exploitation thanks to the ground axe and adze. The occupation of the forest areas of the northern hemisphere, the tropics and islands of the Pacific Ocean, was possible for two reasons. Firstly, ground axes were considerably more efficient than unground ones for chopping trees for houses, canoes, stake structures, and slash-and-burn agriculture; secondly, the grinding technique allowed these tools to be made of rocks which in earlier periods, because of the prevailing technique of flaking, had not and could not play a useful part in the economy, since techniques of splitting, flaking and retouch did not allow them to be worked.

The palaeolithic and mesolithic techniques of flaking, blade-making and retouch permitted the use only of flinty rocks of the quartz family, which are not abundant in nature, and in a whole group of countries are met only as small river pebbles, not suitable for the manufacture of such large implements as axes and adzes. The grinding technique allowed man to employ for this purpose different volcanic granular rocks and even the softer shales and slates.

It is well known that almost all the axes of the northern forest half of Europe are made of slate (*slanets*). The adzes with which the Melanesians and Polynesians dug out their outrigger and double canoes for settling the islands of the Pacific Ocean were made of basalt. Thanks to the ground axe, the earliest slash-and-burn agriculture became possible in the forested areas of the temperate and tropical zones, as well as the construction of pile-dwellings, which represents a great new step forward in the creative activity of man, in the development of society and the formation and strengthening of tribes.

Wood-working had a marked influence on the specialization of tools in neolithic times. In palaeolithic times an axe was a rare occurrence, in mesolithic an adze was added to the axe, although it was an exceptional object. In the neolithic period an axe, adze, and chisel were in use, and in some areas a whittling knife or even a plane (two-handled knife). In addition we can detect specialization in the adzes themselves, the most used tool at this time. There are adzes for rough trimming of wood, for surface work, for deep transverse hollowing-out, gouge and bevelled adzes and so on. Such profound specialization in neolithic wood-working tools is not found everywhere, for only where this branch of manufacture had reached a high degree of development did this become necessary. The same may be said about other forms of manufacture.

With regard to increase of force applied in tools in the neolithic period no major achievements are noticeable, only a fuller realization of striking tools mounted in handles. The latter covers chopping tools (axes, adzes, hoes, picks) as well as stone hammers. In neolithic stone-splitting the wedge and lever were widely employed. Levers were employed for moving great weights, as, for example, the stones used in building megaliths. It has to be recognized, however, that the wedge and lever had been employed in earlier periods, for example in splitting wood and bone and in digging the ground.

As a new achievement of this period at a higher level we must place the first attempt to make practical use of the moving forces of nature, for example the wind. This was the case with the adoption of a sail in some parts of the world (south-eastern Asia and the Mediterranean area). Evidently in neolithic times, particularly in southern Asia (India), the strength of domestic animals (horned cattle) was harnessed for transport.

As regards increasing the rapidity of movement of tools, this tendency in development found its expression in neolithic times in the application of the principle of rotation in some kinds of work. All bodies moving over a certain distance develop great force if they turn on their own axis. In its crudest form the principle of rotation was applied by prehistoric man in such throwing implements as a sling, boomerang, and bolas.

A more valuable application of the principle was found in the adoption of a very simple mechanical drill operated by bow and string. With this device a start was made with quicker and better-quality drilling of wood, bone, shell, stone, and also a swifter method of making fire. It has been mathematically calculated, and is supported by ethnography, that fire can be made in 12–15 seconds with a bow drill, assuming the *savoir faire* and all the rules observed. The bow drill is constructionally related to the archer's bow, but the disk drill, widely employed by tribes in America and the Pacific Ocean area, to the spindle.

The efficiency of drilling with a bow drill is relatively very great; if, for example, two-handed drilling (alternating spin between the palms) was two to three times more effective than one-handed drilling (half-turns), then bow drilling was twenty times more efficient than two-handed drilling.

Further development of the principle of rotation, which had found expression in neolithic times in the form of drilling tools, a little later (eneolithic times) led to the adoption of the potter's wheel and cart wheel, and so produced an exceptionally fruitful enhancement of the speed of movement in other sides of human activity and in the productivity of work.

However considerable may be the technical achievements of the Stone Age it is quite obvious that at the end of neolithic times the development of stone tools had reached a cul-de-sac with all possibilities of further improvement of technology on its existing material basis exhausted. Although cutting tools in the form of composite knives and daggers were a high achievement of stone technology, they were very complicated and laborious things to make and, more important, their efficiency was not great. They consisted of a set of flint blades in a bone haft which was considerably thicker than they were and which always impeded the cutting. In addition a combination of bone and stone did not give toughness and reliability in the more exacting requirements of the work. Flint inserts would break, splinter and fall out. As for stone drills, awls, spear- and arrowheads, they broke just as often as the palaeolithic ones. Man was powerless to alter the internal properties of stone in order to reduce its brittleness.

Especially important in the technology of this period were the chopping tools (axes, adzes, chisels, and picks), which had to retain a large angle of blade sharpness, otherwise they would have broken at the first blow. Some adzes had an edge angle of 45–50°, but the basic mass of chopping tools averaged 55–60° or even more. So in spite of grinding, in spite of bevelling on adzes the efficiency of which was greater, in spite of other improvements noticeable at the end of neolithic times (for example the manufacture of chopping tools of regular geometrical shapes by sawing out the rough-outs), the productivity of work had already ceased to increase. Furthermore, rotary movement, the positive qualities of which were described above, had little prospect of development while wood, stone or bone was employed for the axis.

An escape from the situation that had arisen was found in the extraction and working of metals. Metals are not distinguished by the hardness of some rocks and minerals, and the majority do not possess resistance to chemical reagents. All the same, metals had an incomparable advantage over stone; they possessed plastic qualities and were malleable without breaking, and did

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not splinter under a blow or pressure. The angle of sharpness on an axe or adze blade could be reduced to 15–20° and thus considerably raise the productivity of the implement.

The very process of making the tool achieved a reduction of friction without the necessity for grinding; casting and forging rendered this laborious process unnecessary and left only the sharpening to be done. The degree of hardness of metal was not consistently high, but fusing, forging, and quenching carried out at will could produce the requisite qualities. Forging and smelting could not only give any shape to a metal tool, but also employed it economically, not a scrap of the precious material being discarded.

The ability of metals to assume any shape and acquire a desired hardness gave man the opportunity to develop

and perfect metal tools to an unlimited level of specialization. At the same time, due to its special mechanical quality, one metal tool could in case of necessity replace several stone ones. For example, a one-edged pointed knife of the early Bronze or Iron Age could equally satisfactorily be employed as a meat or whittling knife, but also as an awl, drill, burin or skin knife. The blending of such varied functions in a single stone tool would have been impossible.

In conclusion it should be observed that the study of the laws of development of material culture is an urgent task of archaeological science. A knowledge of these laws reveals the direction of the development of working tools, weapons, utensils, houses, clothing, of different manufactures and of transport, and sheds new rays of light on historical problems.

