PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Neolithic Science and Technology

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II. ANCIENT ASTRONOMY: UNWRITTEN EVIDENCE

Neolithic science and technology

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For northern and western Europe, including Britain, the relevant evidence is much inferior to that available for the ancient East. In the absence of tomb-paintings, relief sculptures and documents, technological processes can be inferred only partially from their end-products, and there is no direct evidence of any general theory derived from observation of natural phenomena. Within these limits, however, it is clear that neolithic communities possessed great skill in 'civil engineering' and an adequate empirical knowledge of soil mechanics. Moreover, the corrected radiocarbon chronology implies the independent invention in the West of the techniques of mining and megalithic construction, and even perhaps of the wheel. In this context an interest in mensuration and in the properties of geometrical figures is not out of place, though no evidence survives for any system of numerical notation.

The purpose of this paper is to furnish a background of information about the state of neolithic technology, against which the evidence for the beginnings of astronomy in prehistoric Europe can be examined in greater detail. The area here considered is that part of Europe which lies to the north and west of a line drawn from Marseille to Helsinki, and south of the 60th parallel. This is the part of the continent which is farthest from the centres of early civilization and technology in the Ancient East and in which, therefore, innovations derived from those centres by a process of gradual cultural diffusion are likely to manifest themselves at a relatively late date, and generally in a modified or even vestigial form. It is accordingly also the area in which independent invention of techniques or ideas at an early date will most readily be detectable.

The period of time here surveyed necessarily has its upper limit at the date at which neolithic culture, economy and technology first became established in any significant part of the area defined above. This was nearly 7000 years ago, or about 4800 B.C. (Clark 1965). The lower limit is less obviously defined, if only because in modern usage the term 'neolithic' has essentially a technological connotation, and in the history of technology innovation can always be more closely dated than obsolescence. For present purposes the lower limit has been taken to be about 1700 B.C., because this appears to be the terminal date, excluding extreme cases, of the sites relevant to early astronomy to which attention has been drawn by Professor Thom (1967, 1971*a*).

At this latter date the stage of technological development reached in different parts of northern and western Europe varies from the Late Neolithic through the Early Bronze Age to the Middle Bronze Age; but it should be understood that the conventional (and largely arbitrary) stages so named conceal the continuing use of techniques of neolithic origin, on which the introduction and early development of copper and bronze metallurgy had relatively little effect.

The dates quoted above, and throughout this paper, are approximations to absolute dates, arrived at by applying corrections to the available radiocarbon dates. These corrections, as is now well known, are necessary in order to eliminate the observed discrepancies between the ages of specimens of ancient timber given by the counting of tree-rings and the ages of the same specimens given by the assay of their residual radioactivity (Suess 1970; Renfrew 1970).

Although the precise values of the corrections appropriate to given radiocarbon ages are still under discussion, it is sufficient for present purposes to say that at the beginning of the period here considered the radiocarbon dates have to be corrected by the addition of about nine centuries, and at the end by the addition of about three centuries.

It is worth noting that in astronomical terms the smaller of these corrections is still significant. For the rising and setting of the full Moon closest to the solstices, for instance, it represents at the period in question a difference in azimuth of rather more than one-fifth of the diameter of the Moon, which certainly exceeds the precision in alinement claimed for early prehistoric astronomers (Thom 1971 *a*). For this reason it is necessary to use *corrected* radiocarbon dates throughout the period here reviewed.

Within the wide limits of space and time defined above, considerable differences can be discerned between one region and another in material culture and in the level of technological advancement; but it is still possible to isolate certain basic elements of technological practice which are common to almost all the neolithic communities of western and northern Europe, and it is to these that special attention is paid below. Most of the examples cited, however, are drawn from Britain or from closely adjacent parts of Europe.

One further general point remains, however, to be made about the sources of our knowledge of the prehistoric technology of northwestern Europe, and about their status as evidence. We are accustomed to think of the ancient civilizations of the Near East as the cradle of science and technology; and the evidence available consists not merely of the surviving end-products of technological processes, but also of contemporary illustrations of the processes themselves. From Egypt, for instance, there are the actual remains of colossal stone statues, which are the end-products of processes of quarrying, carving and polishing, and of techniques of transport and erection; but there are also tomb-paintings and reliefs which show, often in considerable detail, how some of these processes were carried out.

By contrast, for analogous processes in neolithic Europe, which may be typified by the transport of the larger stones of Stonehenge (Atkinson 1960, pp. 116–122), there is no evidence at all. On geological grounds it seems safe to suppose that these stones *were* brought to Stonehenge from a distance of about 40 km; but how this was done is a matter not even of inference, but of pure speculation, based on a somewhat limited knowledge of the materials and mechanical devices which were available at the time in question.

It needs to be emphasized, therefore, how little our knowledge of neolithic technology owes to direct evidence, and how much rests upon a foundation of inference which is far from secure. Moreover, this caution applies with even greater force to our knowledge of the theory which lay behind practice. From Egypt, for example, there is documentary evidence, such as the celebrated Rhind mathematical papyrus, for the state of mathematical knowledge towards the end of the period here in question, about 1600 B.C. By contrast, nothing whatever is known from direct evidence about the state of mathematics in any part of northwestern Europe until after its conquest by the Romans; and what may be inferred from indirect evidence is little enough, and very uncertain. For this reason the term 'neolithic science' can be used, at best, in a very restricted sense.

It is with these provisos, therefore, that the basic common elements of European neolithic technology should be considered. The principal epithets used today by archaeologists to describe neolithic communities are 'stone-using' and 'agricultural'. The first of these reflects the older and literal meaning of the term 'neolithic', current until about 40 years ago and

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signifying that stone, and especially flint, was the best material available for hand tools used for cutting, chopping, boring and scraping; and that where appropriate such tools were shaped by grinding and polishing, whereas at earlier periods they had been shaped by flaking alone.

Already during the preceding Mesolithic stage, and indeed even earlier during the Upper Palaeolithic, a wide range of small hand tools of flint had already been evolved for special purposes, in the working of bone, antler and wood, and for the preparation of leather; and apart from the development of certain special forms of arrowhead, the generality of small neolithic flint tools show no marked improvement on their predecessors. The main technological innovation in this field, which is especially characteristic of the neolithic economy, is the development of heavy chopping tools – axes and adzes – for the felling and working of timber on a massive scale, for which the small light tools previously available were totally inadequate. These heavy tools, made of flint where it was available and of various igneous and metamorphic rocks elsewhere, mark the first use of shaped timber as a constructional and engineering material; and they symbolize a change from the relatively passive symbiosis with the natural environment, which characterizes the hunting, fishing and gathering economies of the Late Glacial and Post-Glacial periods in northern Europe, to a more active effort to exploit, to modify and ultimately to dominate the environment, which typifies the neolithic economy and those which have succeeded it (Cole 1959).

It may be added in passing that the efficiency of these prehistoric chopping tools is much greater than might commonly be supposed. Modern experiments have shown that oak trees of not more than 30 cm diameter can be felled with a flint axe in 30 min, and that for the clearance of forest the efficiency of stone and of iron tools differs by a factor of no more than 2 (Coles 1968, p. 7).

The demand for heavy woodworking tools itself gave rise to the development of two parallel industries producing axes and adzes, respectively in flint and in other types of stone. In both cases the products were distributed, probably in a semi-finished state, over distances of hundreds of kilometres from the source of the raw material. Moreover, in the case of flint the winning of suitable material from the ground involved a whole new technology of mining, very probably invented and developed independently in northern Europe, which is considered further below (p. 129).

In more recent usage, the term 'neolithic' also denotes the practice of agriculture; and it is this aspect of technology which is central to the change in the pattern of human economy called the Neolithic revolution (Cole 1959). The deliberate cultivation of cereals and other crops, and the controlled breeding and maintenance of herds and flocks of domesticated animals, provided either singly or in combination a surplus of stored foodstuffs, which acted as a buffer against the unpredictable vicissitudes of nature and allowed both a growth of population and an opportunity to develop new skills and new ideas.

Throughout the area of time and space here considered, the basis of neolithic life was a mixed farming economy, combining the growing of cereals with animal husbandry (Murray 1970). In its essentials this is a pattern of life at a peasant level which persisted without substantial change until the end of the medieval period in Europe, in which men and women share with animals the role of prime movers, and in which mechanical aids are restricted to simple tools and devices below the level of complexity deserving of the name of machine.

In much of the central part of the region defined, the dominant pattern of settlement was one of villages of substantial timber buildings, often with a tendency towards a common orientation that implies an accepted mechanism of social control (Piggott 1965, ch. 2). In many cases the buildings themselves exhibit a clear division of structure, which presumably reflects a corresponding division of function, between living-space and byre or barn.

The type of agriculture practised appears to have been the 'slash and burn' system, in which an area is cleared of scrub and undergrowth by cutting down and burning, leaving only the bigger timber standing, though probably killed either by deliberate bark-ringing or by the accidental effects of fire. The seed, usually some primitive variety of wheat, is then sown in the soil made powdery and sterile by fire, and enriched by the ashes. The same small plots are harvested, re-sown and re-harvested each year until, after about a decade, the depletion of the soil begins to have an appreciable effect on the yield. At this point the entire village community moves to another site, itself formerly occupied for about a decade by a previous generation and then abandoned. The precise duration of the cycle of occupation and abandonment is necessarily in some doubt; but it seems possible that a community would possess, say, half a dozen separate sites, each of which was occupied for about 10 years and then abandoned for half-a-century, to allow the regeneration of the soil and its plant nutrients.

Cultivation was initially carried out, probably, by hand with hoes and digging-sticks; but already before the end of the 4th millennium B.C. there is evidence for the use of some kind of traction-plough on fields with fixed boundaries and probably, therefore, of a more than temporary character (Fowler & Evans 1967; Evans & Burleigh 1969). This more advanced form of agriculture is appropriate to an environment in which natural forest has already given way in part to grassland, through the combined effects of deliberate clearance and of the prevention, by grazing, of the regeneration of woodland. Moreover, it is notable that in Britain the continental pattern of large nucleated villages is unknown. Instead, the few neolithic houses that have so far come to light are isolated buildings of a size much smaller than their continental counterparts (Piggott 1954, pp. 32–36). This difference must reflect some divergence in social structure and also, perhaps, in agricultural practice, with a greater emphasis on pastoralism in Britain.

The introduction of agriculture has a direct bearing, of course, on the early history of astronomy, since among all the technological innovations made by early man it is farming which most needs a reasonably accurate annual calendar. The need is greatest, perhaps, for the arable farmer, the ploughman; but the opportunities for making the astronomical observations on which any calendar has to be based are certainly far greater for the pastoral farmer, the shepherd who watches his flocks, and the sky, throughout the year and by night as well as by day.

For such primitive astronomers it is the horizon that provides the essential frame of reference – and, moreover, a *distant* horizon, the form of which would remain invariant under small local displacements of the observer. It should be understood, however, that in neolithic times a view of a far horizon was much more difficult to obtain than it is today, because forest, not open grassland or moorland, was the normal and natural habitat of the early agriculturalists. It needs a deliberate effort of will, for those accustomed to the wide open landscapes of today, to put these aside as man-made phenomena, and to think in terms of an environment in which forest was the rule on all but the highest ground, and open spaces of any size, below the tree-line, were the exception. It is easy, but mistaken, to project backwards into the prehistoric past the receding, undulating landscape of the chalk downs of southern England or the bare moorland, treeless and heather-covered, of the west and north; for these are man-made landscapes, many of them not developed before the Bronze Age (Dimbleby 1962, 1967, pp. 141–149).

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What we must put in their place is forest in its natural state, in which the boles of oaks may rise to a height of 27 m before the first lateral branch of any size occurs, and to a total height of 43 m.

Clearance of natural forest of this kind is effected in part by the slow extension of areas of arable cultivation and in part, perhaps predominantly, by grazing. In the absence, initially, of more than small areas of grassland the leaves and twigs of forest trees, and perhaps of elms in particular, were fed to cattle, a process which it has been suggested is responsible for the marked decline in elm pollen which can be seen in pollen diagrams from a number of places in northern and western Europe, soon after the first arrival of neolithic farmers in the areas in question (Troels-Smith 1960). Sheep, goats and pigs, however, are even more efficient clearers of forest in the long run, not because they attack mature trees but because they nibble the tender bark of saplings and dig up their roots, and thus prevent the natural replacement of aged trees by young ones.

For these reasons the progress of forest clearance, and the opening up of astronomically significant horizons, must necessarily have been slow. It is therefore not surprising that almost all the archaeological sites in Britain and Brittany claimed as evidence for early astronomy date from the end of the neolithic period or indeed, for the majority, from the Early Bronze Age.

From the surviving remains it is clear that the most spectacular feats of neolithic technology lay in the field of what may be called 'civil engineering' – in the building, that is, of large earthworks and megalithic structures (Atkinson 1961). Among the earthworks three examples, all British, may be cited to illustrate the apparent limits of achievement.

The first is an extraordinary linear enclosure, about 90 m wide and 10 km long, which runs over the chalk downs of Cranborne Chase on the borders of Dorset, Wiltshire and Hampshire, and is known as the Dorset Cursus. Some twenty similar enclosures are known in Britain, though none of them exceeds 3.2 km in length. The construction of this one, in two stages, involved the digging of a ditch some 20 km in length and between 170 and 200×10^3 m^3 in volume, and the piling of the excavated material to form a bank on its inner side (Atkinson 1955).

The second is the great circular earthwork at Avebury in north Wiltshire, which encloses nearly 12 hectares or about seven times the area of Trafalgar Square in London. Here the volume of solid chalk excavated from the ditch to a depth of some 10 m and piled in an outer bank, was about 100×10^3 m^3 (Smith 1965).

The third example is the most remarkable of all neolithic earthworks, Silbury Hill, which stands $1\frac{1}{2}$ km south of Avebury and is the largest mound of antiquity in Europe (Atkinson 1967). Its base covers 2.2 hectares and its flat top stands 40 m above the surface of the silt which has accumulated in the ditch surrounding the mound to a depth of 9 m. The date of construction is about 2750 B.C. (Atkinson 1969).

Recent excavations have shown that the builders of Silbury Hill had a very sound empirical knowledge of soil mechanics and were aware of the dangers of building a mound, in the manner of a modern mine waste tip, by dumping down the slope from the highest point. Though its exterior provides no hint of it, Silbury has in fact a very complex interior construction. It seems to have been built in successive stages, like a layer-cake, each stage being finished to a level top before the next was started. Moreover, each stage was apparently built in a series of relatively small dumps, working by accretion from the centre outwards; and in each constituent dump the material deposited was raked out into horizontal layers, with the free edges revetted by steeply rising retaining-walls of large chalk blocks. A horizontal section through the mound at any level would thus reveal a pattern of these walls, circumferential and radial, resembling a somewhat 'drunken' spider's web.

It should be added that the builders of Silbury Hill achieved a remarkable degree of accuracy in construction. The initial structures built at the centre of the base of the mound were strictly circular in plan, which allows the centre from which the work started to be determined accurately (Atkinson 1970). It is evident that this centre point was projected upwards as the work proceeded, and was used to ensure the concentricity of the succeeding stages. Careful survey has shown that the original centre at the base, the centre of the flat top, and the centre of the cone which is the best fit to the present surface of the mound all lie within a circle less than 1 m in diameter.

All the excavation involved in these massive earthworks was undertaken with no more than pick-axes of red deer antler, baskets, and the shoulder-blades of cattle used as shovels and scrapers. It is possible that wooden shovels were used as well, but none survives. Work studies carried out during the building of an experimental chalk bank and ditch near Avebury (Jewell 1963) have shown that these primitive tools have about half the efficiency of their modern counterparts – that is, steel picks, shovels and buckets. It is consequently possible to make rough estimates of the labour required for the building of specified neolithic earthworks. For Silbury Hill the figure is 500 men for 15 years. In view of the small size of the neolithic population, this represents a fraction of the 'gross national product' at least as great as that currently devoted by the United States of America to the whole of its space programme.

Engineering skills of a rather different kind were developed in the practice of megalithic architecture, in which large stones, weighing exceptionally more than 300 tonnes, had to be transported and erected. From the south coast of Spain to southern Sweden there is a widespread distribution of tombs for the collective burial of the dead, often used, apparently, for periods of several centuries (Daniel 1958). The walls and roofs of the burial chambers are formed of large stones, and in most cases the chamber was covered by a mound or cairn, although this has often subsequently been removed or eroded.

In a few instances there is petrological evidence that the building-materials were brought from a distance (Giot 1960, p. 94; Piggott 1962, p. 14); and in other cases the size of the structure and of its component stones is so large as to suggest a degree of megalomania. A single example – the Dolmen de Bagneux in a suburb of Saumur on the Loire – may serve as an illustration (Somerville 1928). Its internal dimensions are 18.5 m long, 4.9 m wide and 2.7 m high, so that it is hardly surprising that in modern times it has been used variously as a barn, a garage and a café. The four huge slabs forming the roof together weigh nearly 200 tonnes, and the largest of them is about 7 m square and weighs 86 tonnes. It is no exaggeration to say that even with modern equipment the building of this structure would be a notable achievement. With the primitive devices then available – levers, rollers, inclined planes and ropes (but not pulleys or capstans or windlasses) – it verges on the miraculous.

The handling of large stones was not confined, however, to the building of burial chambers. In both Britain and Brittany there are circles of standing stones, of which Stonehenge and Avebury are the best known, though hardly the most typical. In the same areas there are linear alinements of large stones, the largest being those near Carnac in south Brittany (Giot 1960, ch. 7) which are currently being studied by Professor Thom (1972). The principal

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example, the Menec alinement, contains 1100 stones arranged in 11 rows extending over a distance of nearly 1200 m.

In the same area, a short distance to the east, lie the broken fragments of the largest of all megaliths in Europe, the great menhir of Locmariaquer. It is 20.3 m in length, which is very close to the height of Cleopatra's Needle on the Embankment in London; and it weighs about 340 tonnes, or about 70 % more than the latter. There can be no doubt that originally it stood upright on its broader end; and it has recently been suggested (Thom 1971 *b*) that it served as a foresight for astronomical observations, some of them made over the open sea from a distance of about 16 km. The erection of this enormous stone must be counted among the greatest engineering achievements of prehistoric man in Europe.

With that in mind, it needs to be emphasized that the techniques of moving and raising such huge stones appear to have been invented and developed in northwestern Europe. No support can now be given to the older idea of an origin in the central Mediterranean or even farther to the east. The earliest radiocarbon dates for megalithic tombs come from Brittany, and it is accordingly there that we should seek the origin of this remarkable branch of technology.

Another branch of early technology which was also invented, probably, in northern or western Europe is the deep mining of flint. Neolithic flint mines are known from a number of localities, ranging from Portugal in the west to Poland in the east (Clark & Piggott 1933); but the earliest of them, so far as is known at present, occur at the same date of about 4300 B.C. in Belgium and in Sussex. In the Belgian sites (Clark 1952, pp. 174–175) the miners evidently understood very well the nature of the local geological stratification, and their deeper shafts were excavated through more than 9 m of unstable tertiary and quaternary sands and gravels before reaching the flint-bearing cretaceous beds beneath. In the Sussex mines (Curwen 1954, ch. 6) the shafts were spaced at close but irregular intervals, averaging about 15 m, so that the galleries radiating from their bases formed a continuous network, giving a very high ratio of extraction to waste. It is all the more remarkable, moreover, that this high efficiency was achieved without the use of any timbering, the roofs of the galleries being made deliberately low and arched, so as to be self-supporting. It should be noted too that in both areas the miners clearly knew the quality of flint that they were seeking, and were prepared to dig through up to ten inferior seams before reaching the one which they preferred.

One further invention may possibly have been made independently in northern Europe in neolithic times, namely the wheel; but it must be understood that the evidence on this point is still uncertain, and the hypothesis of independent invention is thus correspondingly speculative.

There can be no doubt that wheeled vehicles existed in ancient Mesopotamia in about 3000 B.C., if not earlier; and the evidence for the making of three-piece disk wheels in the area between the Black Sea and the Caspian has recently been put forward, for dates soon after the beginning of the third millennium (Piggott 1968). It should be noted, however, that the three sections of wheels of this kind are fixed together by very long dowels which pass right through the width of the central portion, and it is doubtful whether the necessary dowel-holes could be bored without the use of metal tools.

In peat bogs in the Netherlands and Denmark, however, one-piece disk wheels have been discovered, carved from the solid and therefore capable of being made without the use of metal tools. The radiocarbon dates of some of the Danish wheels, when corrected, come out soon after 3000 B.C., and those of the Dutch wheels somewhat later. It may well be, of course, that these are imitations, in the context of an inferior technology, of more advanced wheels developed

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somewhat earlier a long way further east; but the possibility of an independent invention cannot be summarily rejected.

The examples cited above have been intended to show that neolithic societies in northern and western Europe were neither as devoid of technical skills, nor as incapable of technological innovation, as has sometimes been supposed. It must be admitted, however, that all of them consist essentially of practical techniques which could have been evolved solely on an empirical or trial-and-error basis. It remains to be asked whether there is any evidence for the generalization of practice to the level of theory or, in short, for neolithic science as distinct from neolithic technology.

The short answer to that question is that there is very little evidence, but that it is correspondingly important. It is clear, for instance, that the builders of neolithic earthworks and megalithic monuments had at least an empirical understanding of field geometry, and were able to lay out on the ground various rectilinear figures which included accurate right-angles (Atkinson 1961); but it is not until the Early Bronze Age that we have unequivocal evidence for something that surpasses the empirical.

Professor Thom (1967, 1972) has drawn attention to numerous examples in western and northern Britain, and rare instances in Brittany, of stone settings of this period which are not circles in the strict sense, but form geometric figures of a more complex kind (ellipses, eggs and 'flattened circles') which cannot possibly be explained away as bad shots at a true circle (which is, after all, the simplest of all regular plane figures to set out with precision). It should be noted, moreover, that the figures in question are not merely complicated in a geometrical sense. They also exhibit properties of shape (e.g. the ratio of the perimeter to the principal diameter) which suggest a special respect for whole numbers and an interest in geometry which goes well beyond the requirements of practical surveyors. In sum, there is clear evidence for some knowledge of pure mathematics. Moreover, the recurrence of the same shapes, but of different sizes, implies the use of some unit of measurement, whether or not this was the megalithic yard deduced by Professor Thom.

In spite of the very compelling evidence that the builders of Early Bronze Age stone 'circles' were pure mathematicians in embryo, it must none the less be admitted that archaeology provides *no* evidence for the existence at this time for any system of numerical notation. In pure geometry the apparent lack of any such notation constitutes only a peripheral difficulty; but in astronomy, where the intervals between observed events have to be recorded, and stored in retrievable form, over periods that may exceed the working life of individual observers, this difficulty becomes much more central. It may be argued, of course, that a system of notation did exist, but that it was used exclusively on perishable materials such as wooden tally-sticks or parchment, so that no trace of it now survives. Such an argument, however, is not merely at variance with the fairly obvious need for long-term, and therefore permanent, record. It also cuts away the foundations of the whole archaeological and historical method of inquiry, which requires that one should deal with the evidence as it is, and not as one would prefer it to be. It is this contradiction, between the positive evidence for prehistoric mathematics and astronomy on the one hand, and the negative evidence for recorded numeracy on the other, which now most urgently needs to be resolved through the combined attentions of prehistorians and astronomers.

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