5. Working Methods and Tools

Few tools have been found in circumstances which relate them directly to the working of skeletal materials. We may attempt, however, by reviewing the known range of implements available to the craftsmen of the period and by examining traces of working observed on certain artefacts, particularly those which remained unfinished, to establish the range of the craftsman's tool kit and the methods he employed in working his materials.

Cutting and Splitting

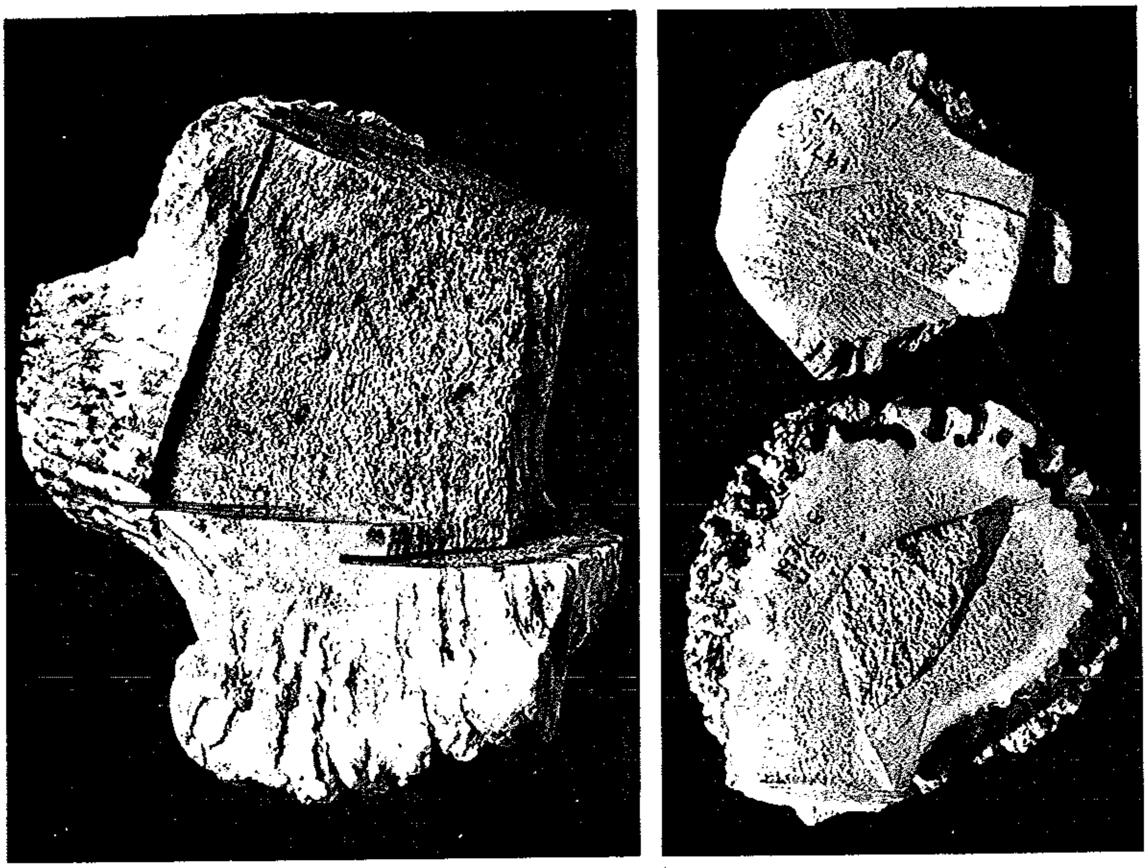
Saws were certainly among the most important implements used in the working of skeletal materials. Much more control can be exercised in their use than in the percussive methods of cutting discussed below. Traces of sawing can be seen, for example, on many discarded antler burrs where they have been separated from the beam (Figure 32). The saw marks show clearly how the material was rotated periodically so that the blade never became too deeply embedded; final separation was usually by breaking. Saws for this type of work must have been comparatively robust: unfinished cuts of 2.6mm width have been observed on certain pieces of waste while, at the other end of the range, the saw cuts may be as narrow as 0.1mm (Ulbricht 1978). Bourdillon and Coy (1980) comment on the absence of saw marks from butchered bones in Anglo-Saxon Southampton, concluding that traces of sawing are, therefore, in themselves an indication of utilisation. Dr Philip Armitage (personal communication) finds no evidence for the use of saws in butchery before the late eighteenth century.

In addition to their use in cutting up material and in shaping certain categories of artefact, saws were also used in applying surface decoration. Close examination of the cuts in schemes of incised decoration shows that they are either V-shaped in section, indicating that they were cut with a knife, or else they are square, in which case they have been saw-cut. Careful measurement of saw-cut decoration has revealed that double saws were sometimes used for this purpose, two blades being mounted side-by-side to produce double cuts which were always inevitably parallel to one another and a fixed distance apart: observations of this feature have been made at Staraja Ladoga (Davidan 1962), Hedeby (Ulbricht 1978) and York (MacGregor 1982a), and the prevalence of decorative motifs based on double lines suggests that double saws were widely used. Salaman (1975) and Rougier (in Wenham 1964) record that among recent comb-makers a double saw or stadda was normally used in cutting the teeth to ensure even spacing (Figure 33). Two short blades were wedged into a wooden back, an interposed metal strip known as a languid (or languet) keeping the separation constant; one blade projected slightly further than the other and acted as a guide when fitted into the slot of the previously cut tooth.

Saws of the Roman period in a variety of shapes and forms have been published (Gaitzsch 1980), but so far only two fragments have been found in Anglo-Saxon contexts, from Thetford, Norfolk and Icklingham, Suffolk, respectively (Wilson 1968, 1976). The Icklingham blade is single-edged and was evidently held in a rigid backing of folded sheet metal; the teeth are quite fine, averaging some 4.6 teeth per cm over 13cm. The blade from Thetford, which is incomplete, has teeth on both sides with frequencies of about 3.7 and 6.1 teeth per cm respectively. In addition, fragments from an iron saw blade found at Lochlee Crannog, Strathclyde (Munro 1879), should be noted.

Berg (1955) has published a fine Viking-age saw with a one-piece bow from Mästermyr, Gotland, while W.L. Goodman (1964), Hrubý (1957) and Kolchin (1956) illustrate alternative knife-like forms resembling modern keyhole saws.

Traces characteristic of axe cutting are common in certain groups of artefacts. At Hedeby it has been noted that the antlers of



a b

Figure 32: Discarded antler burrs exhibiting saw cuts: from (a) Hedeby and (b) York

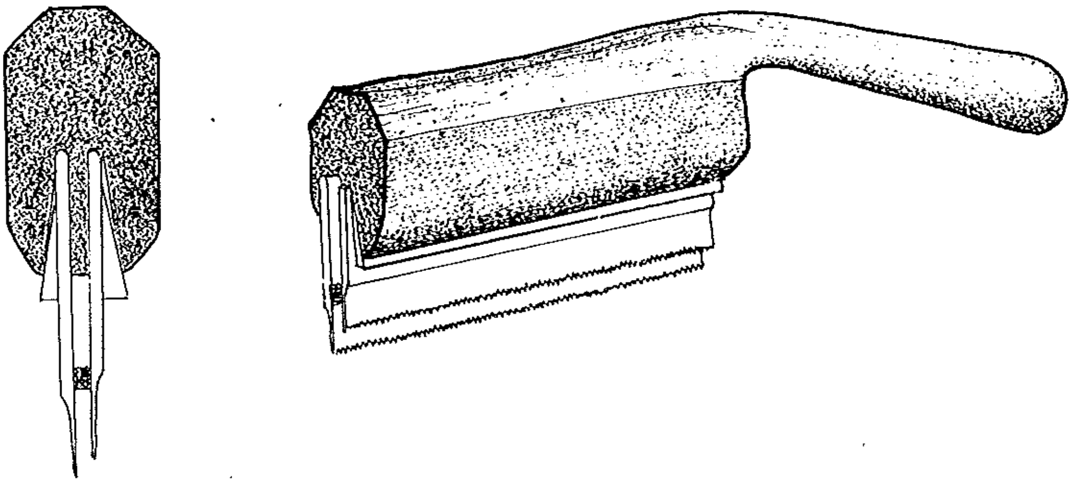


Figure 33: Double-bladed saw or stadda (after Salaman)

slaughtered deer were detached with a number of axe blows to the frontal bones of the skull (Ulbricht 1978); it was clear that the axes in question (which were presumably used by huntsmen or, perhaps, butchers) were much larger than the finer implements which were subsequently used by the antler workers themselves. Horners too made use of axes, recognisable chopping marks having been noted on the bases of discarded horn-cores resulting from the detaching of the horn itself (D.J. Rackham, forthcoming). At the production stage, axes seem commonly to have been used in shaping such items as skates (Figure 76) and socketed points (Figure 93). Axes of varying sizes have been found on numerous sites of the Roman period and later (Gaitzsch 1980; D.M. Waterman 1959; Wilson 1976). Wilson notes that some axes have butts showing signs of having been hammered, suggesting that they were carefully positioned before the cutting blow was delivered by striking the back of the axe. The process of splitting off thin slips of antler for the manufacture of comb tooth-plates must have required precise control of the kind which could have been achieved in this way. Broad chisels, which would have been equally appropriate for this task, are known in the Roman period (Gaitzsch 1980) but are uncommon in later levels: Wilson (1976) notes only one certain Anglo-Saxon example, from Southampton.

Wedges of iron which, along with those of wood, were important items in the carpenter's tool kit (being used to split timbers along the grain) would have been less useful in working more homogeneous skeletal materials. A recent find from Hedeby has, however, given a unique insight into the use of antler wedges in splitting up the thick beams of antlers for use; one such beam section was found with a wedge cut from a tine driven into the cancellous core at one end of the beam (Figure 34), the longitudinal outlines of the desired strips already having been marked out by deep grooves gouged into the compact tissue (Ulbricht 1978).[1] A similar function has been proposed for a series of angular wedges found at Menzlin (Schoknecht 1977). Practical tests have confirmed the efficacy of this technique (Ambrosiani 1981).

Some shaping operations seem to have been carried out with the aid of knives. Traces of their use, in the form of small depressions where chips of material have been sliced off, can be detected on utilised antler tines (Figure 93) and elsewhere. No doubt much of the incised free-hand decoration seen on bone objects — panels of interlace and the like — was executed with knives. The most likely alternatives, fine gravers or chisels, are unknown, although one example of a bone weaving comb of Iron Age date decorated in 'rolled graver technique' is known from Meare lake

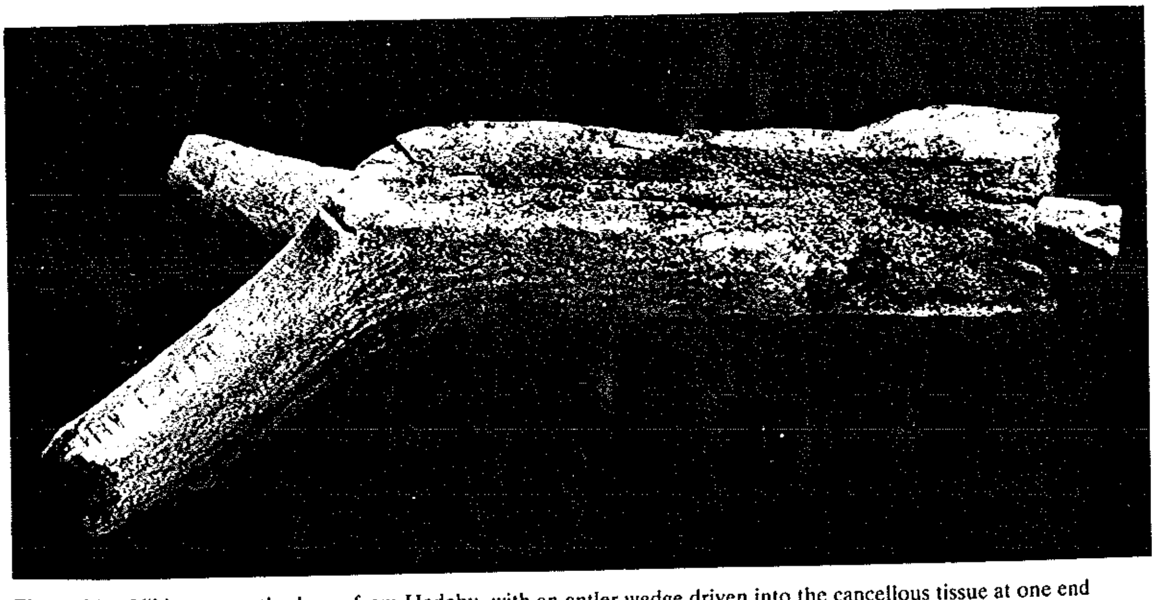


Figure 34: Viking age antler beam from Hedeby, with an antler wedge driven into the cancellous tissue at one end

village, Somerset (Penney 1975). Knives are among the best-attested implement types from all periods and include a variety of blade sizes appropriate to a range of tasks, from intricate carving to heavy chopping duties. One decorative example from Canterbury, Kent (Figure 88n) has been interpreted as a bone worker's knife on account of the care lavished on its ornamentation (Graham-Campbell 1978).

Although they survive only very rarely, draw-knives seem to have played an important part in the working of bone and antler. Flattened facets indicating their use can occasionally be seen on finished objects and concentrations of shavings of antler from Hedeby also provide an indication of their use. Draw knives seem the most likely implements to have been used in shaving down tooth plates for the manufacture of composite combs. Roman examples are illustrated by Gaitzsch (1980) and Anglo-Saxon versions by Wilson (1976).

Smoothing and Polishing

Gaitzsch (1980) reproduces files in a range of shapes and degrees of coarseness from the Roman period, and traces of their use can be detected on items such as bow-splints (Figure 83) and unfinished mounts found at Colchester (Figure 29).

A number of files have been recovered from excavations in Viking age and early medieval Novgorod (Kolchin 1956). Early examples are, as yet, unknown in Britain. Judging from the series of transverse parallel lines which may occasionally be detected on bone objects, some smoothing was done with the aid of a knife blade held cross-wise and pulled along the surface, producing characteristic 'chatter marks'. Otherwise, in the absence of suitable implements, various mineral and organic substances were most probably used for smoothing and polishing. It has already been suggested (MacGregor 1974) that fragments of pumice collected from shorelines in the northern isles may have been used in bone-working. A fragment found in an early tool box from Orkney (Cursiter 1886) may similarly have been used as an abrasive in woodworking. The use of a form of sandpaper, consisting perhaps of a piece of leather, together with quantities of fine sea sand has been suggested on the basis of circumferential striations left on a late Slavic antler awl from Olsborg, Schleswig-Holstein (Hucke 1952). Other minerals which have been used in recent years for working skeletal materials include rottenstone (a decomposed siliceous limestone) and crushed chalk (Andés 1925). Organic alternatives recorded by the same author include powdered charcoal, ashes of bones or antlers, and shave-grass. Hard stems of shavegrass (*Equisetum*) were apparently chopped into finger-length pieces, thirty or forty of which were bound together, softened in water for half an hour, then used for scouring out blemishes in prepared horn. Another possible alternative was coarse fish skin, which was certainly used for smoothing ivory in the Roman period (Barnett 1954); the practice could conceivably have been followed in northern Europe. Present-day horn workers use a succession of increasingly fine polishing media, culminating in swansdown (Griffin, nd). The high degree of polish commonly imparted to such items as the side-plates of composite combs results in all traces of the coarser smoothing stages being obliterated.

Turning

The regular outlines of certain circular-section objects clearly demonstrate that they were lathe-turned. Some of the well-attested series of Roman knife handles with sinuous outlines or with relief mouldings (p. 169) were mass-produced in this way as were cylindrical hinges (pp. 203-5) and mounts. Schmid (1968) mentions also Roman containers (*Buchsen*) and rings produced in this way, and spindle whorls may be added to this list. A waste fragment from Exeter displaying a turned end is dated to the first century (Bidwell 1979). From Colchester, Essex, come two waste fragments with lathe stock centre-marks on the ends, and two lengths of bone turned with spool-and-bead moulding, one of them with an intact un-turned end (Figure 29); both are probably Roman though found in post-Roman contexts (N. Crummy 1981). From the Anglo-Saxon period, the common plano-convex gaming pieces which have been likened to slices cut from billiard balls on account of their symmetry are often said to be lathe-turned (p. 133). It is indeed conceivable that they were made in this way, the roughed-out bone discs being moulded on the chuck of a lathe to which they had been attached in some way. A simpler method might also have been used: a simple forked implement could have been inserted in the twin (or multiple) blind holes which occur on the bases of some of these pieces and used as a handle to spin the roughly-shaped bone disc in a suitably-shaped hollow in a stone. The result would be almost as symmetrical as that obtainable on a lathe. The bone discs closing the ends of certain Roman period handles or the cylindrical gaming pieces from Taplow, Buckinghamshire, may have been lathe-turned or they may have been produced with a profiled centre-bit. The cylindrical walls of the Taplow pieces (p. 134) are more certainly turned.

In Britain pre-Norman lathe-turned bone objects are otherwise limited to a few spindle whorls, but a carefully-made Migration Period box from Pflaumheim, Main-Tauber (R. Koch 1967) can be recognised from its precisely-cut regular outlines as having been turned. Koch has also noted that a comparable cylindrical box was found in a female grave of the seventh century at Gammertingen, Hohenzollern. A turned ivory box found in excavations at Jarrow, Tyne and Wear, may be from the eleventh century (Professor Rosemary Cramp, personal communication).

From the eleventh century onwards the practice seems to have become more common. Among the earliest lathe-turned products of this period are crossbow nuts, examples of which come from Goltho Manor, Lincolnshire in the late eleventh century and from Wareham Castle, Dorset, early in the following century (p. 160). Later in the medieval period, turned nuts of antler (and sometimes ivory) become fairly common. Bone styli or parchment-prickers are frequently made in this way, their machine-made regular appearance distinguishing them from dress pins even when only a fragment survives (pp. 124-5). These also make their appearance around the time of the Norman Conquest and to the same period may be attributed the bobbins of antler ornamented with multiple circumferential grooves (Figure 100) discussed on pp. 183-5. From Hitzacker, Elbe, Wachter (1976) notes evidence for the technique by the thirteenth century at the latest, in the form of a turned needle-case and a rough-out.[2]

No lathes of this period are still in existence although some possible fragments have been found at Hedeby (Dr Kurt Schietzel, personal communication). These would almost certainly have been pole lathes such as were used in the manufacture of wooden bowls (MacGregor 1978a). An illustration of a lathe of this type appears in a thirteenth-century manuscript in the Bibliothèque Nationale, Paris (ms Lat 11560, f. 84(1), reproduced in Salzman 1964) and accounts of them are given by Salzman, Hodges (1964), G.B. Hughes (1953) and Salaman (1975). Smaller bow-driven lathes may also have been used for producing jet and amber beads and rings, and for small items of bone. In the early post-medieval period lathe-turned bone objects, some of them handles, are known from sites such as Basing House, Hampshire (Moorehouse 1971) and Sandal Castle, Yorkshire (MacGregor 1983).

From the late sixteenth century, the development of more efficient lathes, some incorporating steel leaf springs instead of simple poles, led to tremendous advances in turning techniques especially in German ivory-working centres such as Nürnberg. The products of these centres are among the most extravagant examples of baroque taste, featuring hollow-turning of spheres-within-spheres, helical spirals and other astonishing feats of technical virtuosity (Plumier 1749).

Drilling

Traces of the use of drills are commonly found on artefacts of skeletal materials, particularly on articles of composite structure such as combs (p. 73) and caskets (p. 200).[3] Although a considerable number of early drill-bits are known (Peterson 1951; Wilson 1968, 1976) most of them are shell-bits (or spoon-bits) which, although effective on fibrous material like wood, would make little impression on bone, antler or ivory. Gaitzsch (1980), however, illustrates twist drills as well as spoon-bits from the Roman period. The punches which have been postulated as having been used for perforating bone and antler (Hrubý 1957) would seem to be very questionable; for these dense and compactly-structured materials, implements incorporating well-defined pointed cutting ends would have been more appro-

Figure 35: Rosary bead maker using a bow-driven lathe or drill, from the fifteenth-century *Hausbuch der Mendelschen Zwölfbrüderstiftung* (f. 13r) (For an account of the complete manuscript see Treue *et al.* 1965)

priate, in the form either of angular-section awls for smaller perforations or of centre-bits, in which the cutting element describes an arc around the centre point, for larger holes. While awls are among the most common implements on archaeological sites, none has been found in circumstances specifically associated with bone working. Centre-bits, on the other hand, are unknown from early contexts, although tools employing the principles of the centre-bit were certainly used for the production of ring-and-dot ornament from the period considered here (see below). A fifteenth-century German illustration of a rosary bead maker shows a bow-driven horizontal drill with radiating spikes at the tip, which would be ideal for this purpose (Figure 35).

Implements of a rather different type, with larger dimensions, may also be postulated on the evidence of discoid playing pieces (Figure 72), as well as spindle whorls cut from jaw bones (Figure 101). A large series of jaw bones (bovine mandibles) has been recovered in Schleswig (Figure 36), each drilled with one or more holes from which such pieces have been cut (Ulbricht 1980a). Of necessity, the material which originally occupied the area within these perforations was not destroyed in the drilling process, so that some form of hollow bit must have been used. Many of these discoid pieces have no deep central indentation as might have been made by a centre-bit. Instead it is necessary to envisage an implement resembling a modern crown saw or a surgeon's trepanning saw, each of which has the form of a hollow cylinder with a toothed cutting edge and can be mounted on a simple handle as an auger (Salaman 1975). Although they are uncommon finds, a few examples of such tools are known from the Roman period, when they are thought to have been exclusively used in surgery: examples come from a physician's grave at Bingen (Como 1925; R. Waterman 1970; see also Figure 37) and from Niederbieber (Gaitzsch 1980), both in the Rheinland-Pfalz. There seems to be no reason why craftsmen working in the very materials for which trepanning saws were developed should not have had equal access to them and, indeed, it is difficult to account for the manufacture of discoid gaming counters without such an implement.

Scribing

Apart from saw- and knife-cut ornament, the most commonly encountered forms of decoration on bone and antler objects are inscribed ring-and-dot motifs. Occasionally, the concentric ring elements display an irregularity which indicates that they were executed freehand (MacGregor 1974), but the vast majority are perfectly symmetrical and must have been produced with an implement of the centre-bit type. This type of decoration is occasionally referred to as 'compass-drawn'[4] but simpler tools with fixed-radius scribing points would seem to be more probable than variable compasses. Equally, symmetrical double-ring-and-dot motifs (Figure 107) show that some of these implements may have had two or more scribing points at differing radii, although two single-toothed implements of differing dimensions could have been used successively to the same effect. The concentric rings sometimes incised on the surfaces of discoid playing pieces

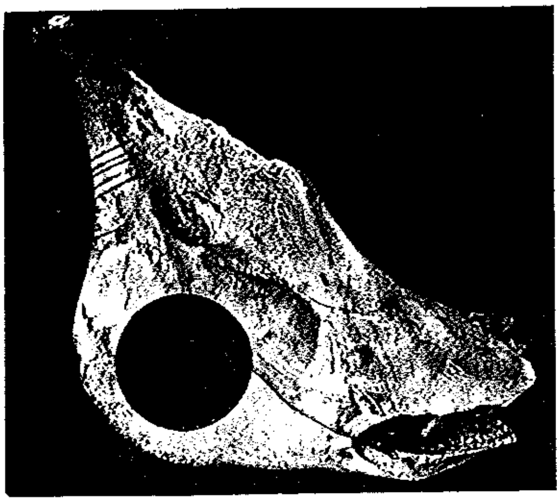


Figure 36: Early medieval bovine mandible from Schleswig with disc excised to form a spindle whorl or gaming piece

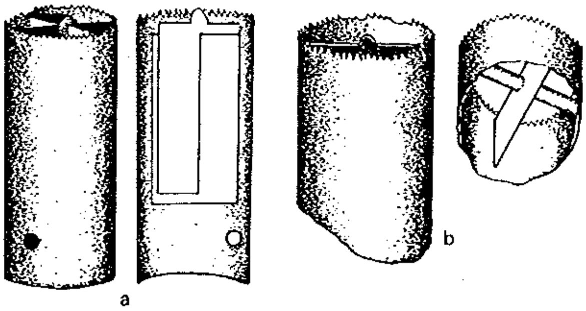


Figure 37: Roman trepanning or crown saws of bronze (scale 2:3) from Bingen (after Como)

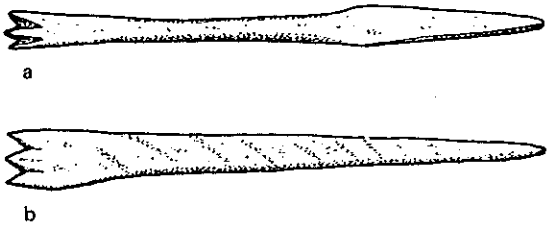


Figure 38: Centre-bits or scribing tools from Slavic settlements at Staré Město (after Hrubý) and Levy Hradec (from Tempel, after Pič) (scale 3:4)

(Figure 72) and spindle whorls (Figure 101) carry similar implications. Few implements capable of producing ornament in this fashion have so far been noted from an archaeological context: Hrubý (1957) has published an iron tool shaped rather like a drill-bit, terminating in a central point flanked on either side by another point (Figure 38a); the lateral points are of unequal length but seem to be equidistant from the centre, so that in use only a single circle would have been described around the centre point. A similar implement comes from Levy Hradec, Bohemia (Figure 38b).

A second type of scribing implement may also be postulated. This produced incised lines at a fixed distance from the edge of the material, so that we may envisage a stop which followed the outline of the piece and one or more teeth which executed the decorative grooves. The principle involved is therefore similar to that of a present-day carpenter's mortice gauge, except that there was unlikely to have been any facility for adjustment. Evidence for the use of these implements comes from casket mounts and combs: in the latter case, the border lines which follow the profile on certain Viking age combs (Figure 50a-b) may be noted and also, more strikingly, the double border line found on some end plates of complex outline from the same period (Figure 50d). Grooves of this type are usually flat-bottomed in section, suggesting that a small chisel-like point was employed. No appropriate implements have yet been found.

Rouletting

A recent find from excavations at Coppergate in York has added a new technique to those recorded for bone decoration. The object (Figure 107c) is a wooden box lid decorated with bone strips cut from split ribs which, in turn, are ornamented with zig-zag and linear patterns of impressed dots, having the appearance of being rouletted.[5] This technique, which is more appropriate for soft materials such as leather or (unfired) pottery, may have been used in conjunction with one of the softening methods discussed below (p. 63): only with prior softening does it seem likely that sufficiently deep impressions could have been made with a rouletting wheel. No extant examples of the latter are known.

Gauging

For certain tasks, notably the production of tooth plates for composite combs, the use of some sort of gauge or template seems to be implied. As noted below (p. 75), the teeth on combs of this type were invariably cut after the blanks had been riveted between the side-plates. In order that the junctions between adjacent tooth-plates always coincided precisely with one of the saw cuts for the teeth, it seems necessary for the blank tooth-plates to have been cut to predetermined sizes corresponding to whole numbers of teeth. This could have been achieved either with a rule or gauge on which the appropriate spacings had been marked, or else with a series of templates of suitable dimensions. One comb from Abingdon (Figure 39) displays scribed lines running from the ends of the saw-cut teeth; they are extremely irregular compared with the teeth themselves, however, and seem more likely to be of secondary origin than to be marking-out lines. The more regular lines to be seen on the end-plate of a comb from Elisenhof, Schleswig-Holstein, illustrated by Tempel (1969) are more certainly guidelines for the saw.

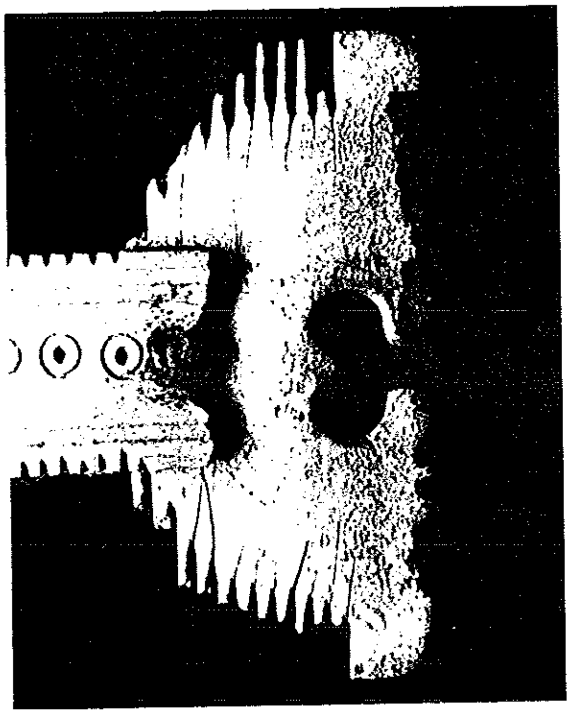


Figure 39: End-plate from a double-sided comb found at Abingdon, Oxfordshire

Clamping

One type of implement has tentatively been identified as having been used to secure small pieces of material while they were being worked. Characteristically, these implements consist of two elements of antler (Figure 91) joined by a stout iron rivet. Each antler piece is D-shaped in section, the flat edges being contiguous; viewed from the side, the opposed faces of the antler grips diverge from one another towards one end. The method of use, as suggested by Jankuhn (1943), is for the material being worked (such as tooth-plates for composite combs) to be inserted between the open jaws at one end. These are then made to clamp around the object by means of a wedge hammered into the opposite (closed) end, the iron rivet marking the fulcrum point. One of the clamps discussed below, from Ytre Elgsnes, Norway, was found along with other tools in what was originally interpreted as a smith's grave (Simonsen 1953); more recently, Tempel (1969) has suggested that the entire tool-kit might be considered equally appropriate for a comb-maker.

Riveting

Composite items of skeletal materials were frequently assembled by riveting. The mounts discussed below (p. 197) were attached to their wooden caskets or articles of furniture in this manner and all combs of composite construction (p. 82) were assembled by this technique. Two alternative methods of riveting can be found in each of these groups of objects, one using bone (or antler) and the other metal. The use of bone pegs has the advantage that incised decorative schemes can be continued over their heads; it should be noted, however, that the use of bone rivets on combs is both rare and largely limited to the Celtic world. Iron rivets were most commonly used for all purposes. A few Early and Middle Saxon items, such as the Taplow gaming pieces (p. 134), make use of bronze rivets, but these remain uncommon until the beginning of the medieval period, when the rivets of combs, for example, are more frequently of bronze, and also used in greater numbers (p. 75).

Softening and Moulding

The techniques already mentioned in this section have been applicable equally to all the raw materials under discussion. On the question of softening and moulding, however, the differing physical properties of these materials demand individual consideration; only bone and antler may be considered together for these purposes.

Two objectives may be distinguished in this context: softening may be induced temporarily either with a view to altering the shape of the artefact (or the raw material) before restoring it to its original hardness, or it may be used to facilitate the process of shaping or decorating by making the material easier to cut.

Bone and Antler

As a preliminary to bone-working in the Roman period it has been suggested (Schmid 1968) that softening in water would have been a normal practice. Discussion of whether and by what means bone and antler may have been softened in both earlier and later periods has been most intense among archaeologists in Poland.[6] In particular, K. Żurowski has conducted practical tests over the past thirty years and published his findings in a number of papers (Żurowski 1953, 1973, 1974). Żurowski's interest was first aroused by traces of working (particularly in the form of knife-cuts) on antler artefacts: he deduced that, since antler is a comparatively hard material, these cuts could have been made only after preparatory softening of the raw material. The fact that preliminary softening is a normal practice among antler and horn workers in contemporary Slavic folk cultures had come to the notice of other archaeologists and ethnologists (e.g., Moszyński 1967); inadequate appreciation of the quite different properties of these two materials has, however, led to inconclusive results being obtained when these methods were applied indiscriminately during experimental attempts to induce softening (Żurowski 1974).

In order to bring about temporary softening of bone and antler, the material may be immersed in an acid solution: present-day exponents of Russian folk art use vinegar (acetic acid) in solution for this purpose. Looking for naturally occurring acids which would have been available to bone and antler workers in the past, Żurowski settled on sorrel (*Rumex* sp.), a plant rich in oxalic acid, the remains of which have occasionally been excavated from layers of early medieval date (Żurowski 1974). Having prepared a soured broth of sorrel leaves, he immersed a red deer antler in the solution; every two days attempts were made to cut it with a knife and in this way he was able to demonstrate progressive softening until, after six weeks, the antler could be cut like wood. On being removed from the solution and allowed to dry, it regained its original hardness within four days. Further experiments by the same author employed sauerkraut, sour milk and buttermilk, with which greatly accelerated reactions were obtained, the antler becoming soft within two to three days (Żurowski 1973).

Also according to Żurowski (1974), reversible reactions could be obtained with diluted chloric acid as well as a range of organic acids, including acetic, lactic, propionic and butyric acids, and with various preparations based on cabbage, gherkins and the like. The roots, as well as the leaves, of sorrel, were said to be effective for this purpose (Kluk, quoted in Żurowski 1974). (Non-reversible reactions were said to be induced by solutions of tartaric, oxalic[7] and sulphuric acids.) The chemical mechanism involved in the reversible reactions is given by Żurowski as follows:

Softening

$$2[Ca_3(PO_4)_2] \,.\, CaCO_3 \uparrow \underset{\text{acid}}{\overset{CO_2}{\longrightarrow}} CaHPO_4$$

Hardening

$$2H_2O \quad \underset{\text{from the air}}{\xrightarrow{\quad CO_2 \quad}} \quad 2\,[CA_3(PO_4)_2]\; CaCO_3$$

Żurowski's attractive hypothesis has been adopted by a number of his colleagues. Cnotliwy (1956, 1969) has suggested that the standard method of antler-working in Slavic period and medieval workshops was for the material to be first of all sawn into appropriate lengths and subsequently softened, before further shaping with a knife or draw-knife. Hrubý (1957) states that antler finds from Moravia confirm the practice of softening in sorrel-derived acid, while Schoknecht (1977) concludes that softening pits would have been a normal adjunct of comb-makers' workshops. Żurowski himself interprets pits full of antler fragments found at Błonie near Warsaw as acid softening pits.[8]

Considering the complex and intimate nature of the union between the organic and inorganic elements in bone structure (pp. 2-4) these claims seemed inherently unlikely to be valid, for, having once removed mineral from the bone it would be quite impossible to replace it. A series of tests were therefore carried out by the writer in association with Professor J.D. Currey, in order to clarify the situation. Using the method for establishing the modulus of elasticity outlined on p. 27, a number of standard test specimens were manufactured from a single shed antler of red deer. These were then immersed in bulk quantities of lactic acid (sour milk, pH 4.32), acetic acid (malt vinegar, pH 2.83) and oxalic acid in the form of a solution of sorrel leaves (*Rumex acetosa*, pH 3.57), for periods of six, twelve, twenty-four, forty-eight and ninety-six hours respectively, before being loaded in three-point bending on an Instron table testing machine. Full details of the results will be given in a forthcoming paper, but it can be said here that none of the methods of chemical softening discussed above can truly be said to be reversible. All the acids mentioned act on the bone by removing the mineral fraction, the action progressing from the outer surface of the bone to the interior. Whereas the consequent impairment of the structure might be acceptable in the making of, for example, folk-art carvings of the present day, it seems unlikely that it could have been tolerated in the manufacture of implements or items such as combs, particularly when (as argued on pp. 28-9) advantages of a lower order of magnitude were appreciated and seized on. Two recent accounts of bone and antler working (Ambrosiani 1981; Ulbricht 1978) reject the possibility of chemical softening. In one case (Ulbricht 1978) after practical experiments with sorrel softening the antler was found to have been robbed of its resilience and left dull and lifeless. To these objections may be added another: if, as suggested on pp. 49-50, comb-workers operated on an itinerant basis all the year round, there would have been no attraction in a working method which demanded several days or even weeks of preliminary softening, particularly if the operation was dependent on the seasonal availability of the softening agent.

A degree of softening sufficient to account for the working traces which prompted Żurowski's investigations is in any case attainable by the simple expedient of soaking the tissue in water. Long shavings were easily detached with a knife from the antler shown in Figure 40a, after forty-eight hours softening in cold water. After soaking for a similar length of time, a second piece of antler was placed in boiling water for fifteen minutes, after which it could be cut with even greater ease (Figure 40b). Boiling for seven to eleven hours, as practised experimentally by Szafrańsky (quoted in Żurowski 1973), is not only unnecessary but is likely to impair the quality of the tissue by leaching out collagen. Boiling in oil, as postulated by Cnotliwy (1956), would be equally unnecessary, not to say costly.

The alternative aim in inducing softening, namely to allow the bone or antler to be bent into a new shape before rehardening, may now be considered. Prompted by discoveries of Neolithic armlets made from split ribs which had been bent into an arc,[9] Żurowski (1974) set about reproducing the softening processes which were clearly involved. He was able to replicate a bone armband of this type by splitting a bovine rib and immersing it in a bath of sour milk: after some days he was able to bend the plate of bone into a ring, which was then bound up and allowed to dry. When the bindings were removed, the plate was found to retain its new shape.

Evidence for some similar practice is more common in the Roman period when narrow armbands or bangles of bone or antler (pp. 112-13) were made by bending a thin strip into a ring and securing it in position with a bronze band. Unfortunately, nothing is known of the medium used for softening these bracelets.

From later periods there appears to be no evidence of finished items produced by bending in this way, but on the basis of thirteenth or early fourteenth century finds from Dobra Nowogardzka, Cnotliwy (1969) has suggested that long strips (some of 19cm or more in

a b

Figure 40: Slivers cut with a knife from red deer antler softened in water: (a) after 48 hours soaking in cold water (b) after 48 hours soaking in cold water followed by 15 minutes in boiling water

length) cut from naturally twisted antlers may have been straightened after preliminary softening and before manufacture into casket mounts.

Softening for the purposes of bending can hardly be denied, for the evidence is unequivocal. The method used may have been one of those mentioned above, but there is no means of telling. For the ornamental purposes to which these pieces were put, consequent impairment of the raw material's mechanical properties may not have been considered unacceptable.

Ivory

Elephant ivory has a unique combination of working properties which are considered exemplary by artists and craftsmen all over the world, and it seems unlikely that it would normally have been subject to preliminary softening before carving in the normal way. Digby (1926), however, notes that Siberian mammoth ivory was softened in very hot water prior to working by native craftsmen and Sandys-Wunsch (nd) recommends soaking mammoth ivory in vinegar for two or three days prior to carving.

Evidence for softening elephant ivory for special purposes has also been noted elsewhere in the past. Panels or tablets of ivory measuring up to 75cm square were much favoured by eighteenth-century portrait painters such as Ross, Thorburn and Newton, who found that they made excellent vehicles for their art. These dimensions far exceed those which could be achieved by cutting cross-sections or longitudinal-sections from tusks, and clearly result from an alternative method of production. Williamson (1938) explains that these panels were cut from around the circumference of the tusk after the ivory had been softened with phosphoric acid; while still soft they were flattened out under pressure, washed and dried, after which they regained their former consistency. H.E. Cox (1946) states that the phosphoric acid should be in solution of specific gravity 1.130 and that ivory, once treated in this way, can be rendered soft again merely by immersing it in warm water. Volbach (1952) mentions that a method of softening and flattening ivory had also been used by craftsmen in the classical world, but gives no details of the method employed.[10] Theophilus, on the other hand, gives a range of techniques for ivory softening as used in the eleventh century, including heating in wine or vinegar or over a fire, annointing with oil and wrapping in leather (Hawthorn and Smith 1963).

Horn

As already stressed, the composition of horn is quite distinct from that of antler and hence the methods employed in working it can be very different. This is particularly true in the case of softening and moulding, which have for centuries been essential processes in the horner's repertoire.

Rendering horn soft and malleable is achieved simply by the application of heat, although delicate control is needed to avoid damaging the material. (No chemical change is therefore involved here, although Żurowski (1974) mentions an alternative method of softening in which horn may be boiled in a solution of wood ash.) Following some weeks of soaking in a tub or pit, the keratinous horn sheaths were separated from the bony cores and set to boil in a cauldron. After one to one-and-a-half hours' boiling, the horn was taken out and held over a fire with a pair of tongs or with a special toothed warming tool (Andés 1925), to evaporate the excess water and further soften it by gentle and even application of heat; it was then ready for 'breaking' or opening. According to the account of a York horner working in the first quarter of the present century (recorded in Wenham 1964), one of two methods of cutting would normally be used, depending on the desired shape of the resulting horn plate: after the solid tip had been removed, the cut could be made either in corkscrew fashion, to produce an elongated rectangle when opened out with the aid of a pair of tongs, or else a straight cut could be made from the tip to the base, giving a squarish plate (Figure 41). Andés stresses that the cut is normally made along the weakest line, namely the inside of the curve. The whole of the above process had to be carried out quickly and efficiently, while maintaining the appropriate temperature: too much heat would scorch the horn and not enough would result in it readopting its former curvature.

After some preliminary trimming and removal of blemishes with the aid of a scraping knife or spokeshave, the plates of horn could then be returned to the cauldron for re-softening, after which they were further pressed

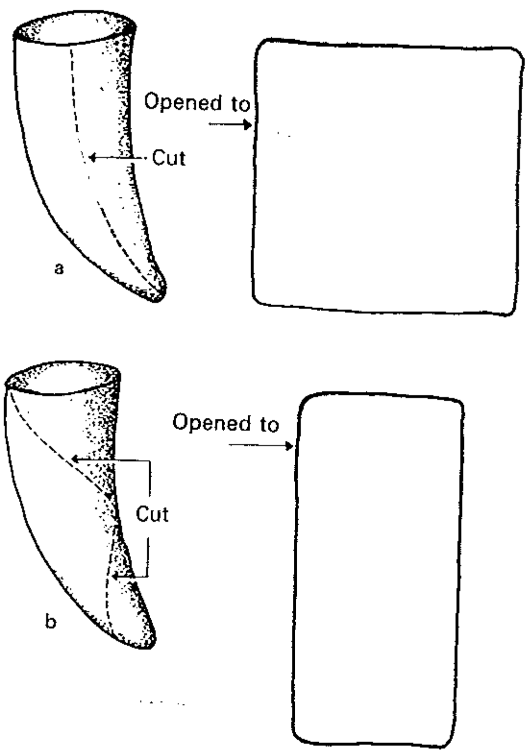


Figure 41: Alternative methods of horn breaking, as practised in early twentieth-century England (after Wenham)

between heated iron plates, the smooth surfaces of which had been smeared with grease.[11] Final smoothing and trimming was then all that was necessary before the plates were ready for manufacture into items such as combs, boxes, etc.

Exceptionally thin and translucent plates, such as were used in the windows of lanterns (hence, probably, the Middle English form *lanthorn*), were produced by selecting suitably light horns, soaking them in water for about a month, and then delaminating or splitting them into two or more leaves before subjecting them to pressure as above. Andés (1925) mentions that translucency could be improved by smearing the horn plates with oil and warming them over a fire, or else by boiling them in three parts water to one part waste fat, before pressing them for half an hour and finally laying them in a dish of cold water. A fine globular lantern incorporating plates of this sort is described by Way (1855) and several smaller lanterns are illustrated by Hardwick (1981). Individual leaves of horn, bearing marks from preparatory grinding and polishing processes, have been recovered from Tudor levels at Baynard's Castle, London (Armitage 1982).

Sheets of horn could be welded together by pressing them between greased plates at temperatures higher than those employed in the processes described above (Wenham 1964). The steel plates were heated over a fire and placed in a press, where tallow was applied to them. When the temperature was judged to be right, the horn plates were introduced and pressure applied. After a few minutes the plates would begin to 'run' and the pressure would be further increased. On cooling off, they would be stuck fast together, provided the appropriate delicate balance of temperature and pressure had been maintained.

Andés (1925) gives a recipe for enhancing the 'elasticity' (toughness) of horn, involving a solution of three parts nitric acid, fifteen parts white wine, two parts vinegar and two parts rain or river water. After treatment in this way, it is said that horn combs could withstand being trodden on without breaking.

The methods described here have been in common use for at least the past three centuries and many of them probably have much earlier origins. Blümner (1879) quotes Pausanius on the softening of horn in the second century AD, and mentions a striking range of utensils known from classical literary sources. In most surviving early artefacts in which horn was used other than in its complete form, too little survives of the organic material to demonstrate whether it had been worked in this way. The plates on the Benty Grange helmet (pp. 154-5), however, were judged (Bruce-Mitford and Luscombe 1974) to have been softened and bent into shape. A fragment of thin horn with incised decoration, perhaps originally from a box or casket, found in a medieval context at York (Figure 107b) may be an early piece of pressed or delaminated horn. The series of horn combs with riveted side-plates (Figure 52) seems to consist of the entire thickness of the horn, which has simply been flattened and filed.

The full potential of horn as a versatile raw material was perhaps only fully recognised during the last century; several British Patents — e.g., 6402 (1899), 1021 (1908), 163, 219 (1920) — have been filed for processes involving the manufacture of such diverse items as umbrella handles, cigar holders and electrical switch covers from small scraps or powdered horn which, after treatment, was reconstituted and moulded in dies under heat and pressure.

Colouring

Some evidence can be mustered to show that colouring was occasionally used to enhance the appearance of objects made from skeletal materials. Occasionally colour contrast was provided by the employment of sheet-metal backing behind a pierced, openwork design (pp. 91, 199), while at other times colour was applied directly to the material. Green seems to have been a particularly favoured colour: green-stained pins have been recovered from Roman excavations at Rochester, Kent (Harrison 1972) and York (MacGregor 1978a), and again in York, a Viking period buckle, highly polished and deeply coloured to look like bronze, was found in early excavations in the city (D.M. Waterman 1959; colour illustration in Roesdahl *et al.* 1981). A green-stained die from Lincoln (Lincoln Archaeological Trust, unpublished) came from recent excavations in Flaxengate. Traces of red staining have been noted on a Migration Period comb from Holzgerlingen, Württemberg (Veek 1931); on the Fife casket (Anderson 1886); on the Lewis chessmen (Madden 1832); and on a number of ivory book covers.

Other instances occur of colour being applied as inlaid pigment, commonly used to highlight incised decoration on Roman age bone carvings from Egypt (Marangou 1976). Schmid (1968) has noted the use of black, seemingly 'ivory black' mixed with beeswax, to emphasise incised ornament on Roman hinges (p. 203) from Augst, and on contemporary bone objects in the Naturhistorisches Museum, Basel. Veek (1931) mentions the use of white 'incrustation' to heighten incised decoration on a Migration Period comb from Oberflach, Württemberg, and traces of blackening have been found on a Viking comb from Birka in Sweden (Kristina Ambrosiani, personal communication). In England there appears to have been a fashion for filling incised details on certain Romanesque ivories with black pigment (Beckwith 1972) and finds of dice and playing pieces from Ludgershall Castle, Wiltshire, with traces of black, white or red pigment show that the technique was extended to quite mundane objects (MacGregor, forthcoming).[12] A number of Roman bone pins are known which have their shanks sheathed in gold leaf, a treatment more commonly given to carved ivory book-covers, playing pieces and the like; it was also applied to the clothing of carved figures and to other details on the bone-mounted caskets of the Embriachi (Dalton 1909).

According to the *Plictho* of Gioanventura Rosetti (written in Venice, 1548), bone could be dyed green in a solution of red vinegar containing copper fillings, Roman vitriol, roche alum and verdigris (Edelstein and Borghetti 1969). An alternative method mentioned by the same author was to place the bones in a copper vessel containing a mixture of goat's milk and verdigris, which was buried for several days in a mound of horse manure to keep it warm. Theophilus, writing in the first half of the twelfth century, recommends the use of madder for staining bone red (Hawthorn and Smith 1963), while Andés (1925) and Forbes (1955) give a wide range of vegetable and other dyes suitable for colouring skeletal materials, some of which would have been available to the medieval craftsman. D.V. Thompson (1935) lists numerous documentary sources giving medieval recipes for dyes and pigments. W.E. Cox (1946) notes a range of organic and inorganic dyes which were available to Chinese ivory carvers, some of which could also have been utilised in the West.

Evidence from Industrial Waste

On the basis of large amounts of waste material and half-finished pieces, Ulbricht (1978) was able to reconstruct in some detail the various methods of utilisation employed by the Hedeby antler workers (Figure 42). Comb-making was the principal activity represented, but other items were also produced, often utilising those parts of the antler which were unsuitable for combs. Although treatment varied according to the particular form of the antler concerned, the usual starting point was the removal of the tines by sawing them flush to the beam. In general, the lower parts of the beam were reserved for side-plates, appropriate strips of compact tissue being produced by cutting off a suitable length of beam and quartering it with a saw, the irregular outer surface and the cancellous material from the core being subsequently smoothed away. An alternative method, often employed when an irregular number of strips was to be produced from a single length of antler, was for the plates to be outlined with longitudinal grooves cut through the compact tissue and subsequently detached with the aid of an antler wedge driven into the cancellous centre (Figure 34). Side-plates might also be produced by selecting a suitably shaped tine and sawing it in half lengthwise.

The upper parts of the beam, which tend to adopt a twist, were usually reserved for sawing into shorter cylindrical lengths, from which tooth-plates were detached either by sawing or splitting off plaques of compact tissue. Other items such as handles or wedges might occasionally be produced from tines. The dense tissue within the burr produced ideal material for spindle-whorls or gaming pieces, while gaming pieces and dice were also cut from the pedicles attached to the antlers of slaughtered deer.

Ulbricht's analysis of the Hedeby material is the most systematic exercise of its kind yet undertaken, but elements of the same techniques have been noted wherever large-scale antler-working has been discovered. Ambrosiani (1981) has produced a break-down of the waste material from Ribe, showing that it conforms to a large extent with the Hedeby finds; she notes some points of particular interest. The special favour with which pedicles were regarded as raw material for gaming pieces and the like was illustrated by the fact that only one intact pedicle was found, compared with twenty-nine burrs from which the pedicles had been sawn. A further disparity among the finds concerned the proportion of unutilised tines to burrs: whereas the average red deer antler might have sported five or six points, Ambrosiani noted that waste material contained only twice as many tines as burrs, indicating that a significant proportion of them had been utilised. The relatively low numbers of cancellous fragments found in all but one area at Ribe were tentatively explained (Ambrosiani 1981) as resulting from the dumping of this material elsewhere or, perhaps, the extensive use of rasps and files in its removal, which would leave only small crumbled particles.

At Lund a somewhat different method of removing the cancellous tissue must have been adopted, as triangular core fragments from quartered beams are common: Christophersen (1980b) notes over four hundred examples and produces an explanation of their formation.

Other accounts of waste material, providing fewer details, but containing at least some elements in common with those already mentioned, cover the Baltic settlements from Schleswig-Holstein to Gdansk (Cnotliwy 1958, 1970; Hucke 1952; Schoknecht 1977; Schuldt 1980), Moravia (Hrubý 1957) and England (MacGregor 1978a, 1982a).

Notes

1. Cnotliwy (1969) noted similar grooving on antlers from Dobra Nowogardzka, Szczecin, but there, in the late thirteenth or early fourteenth centuries, final separation of the strips was by sawing.

2. An unstratified bovine metatarsal (Figure 29c) found at Billingsgate, London (M. Rhodes in D.M. Jones 1980) represents a typical waste product of the turning process; the outer surface has been roughly whittled before being turned on the lathe, the articular ends finally being sawn off and discarded.

3. K.A. Wilde (1953) suggests that the rivet holes on combs from Wolin have been burned rather than drilled, but this seems unlikely. No contemporary evidence for this practice has been found elsewhere.

4. It is also occasionally said to be punched (see, for example, Dryden in *Archaeol. J.* 39, 422; Galloway 1976) but this method would probably not be effective. Schoknecht (1977) suggests that it could have been used after the material had been softened, but there seems to be no evidence for this. According to one report (*Britannia* 2, 299) a Roman bone comb from London bears the maker's name stamped on either side, but the comb is in fact made of wood.

5. I am grateful to Mr D.J. Rackham for pointing out this feature.

6. Hrubý (1957) mentions evidence of softening from Czechoslovakian finds, but does not elaborate on the matter.

7. Oxalic acid is in fact the principal softening agent contained in sorrel, which Żurowski describes elsewhere as the most likely *reversible* acid.

8. There seems to be no reason to interpret these as other than rubbish pits.

9. For these Neolithic armlets made from split ribs see Czerniak *et al.* (1977) and Maciejewski *et al.* (1954).

10. The technique of softening ivory seemingly had an even greater antiquity, however, as is suggested by a further instance dating from the upper Paleolithic period and found at Vladimir, east of Moscow. In this case, the objective was to soften the ivory with a view to eliminating the natural curvature and, since the tusk in question was from mammoth rather than elephant (Żurowski 1973), the curve would have been considerable. A spear made entirely of mammoth ivory was found in association with two skeletons, the spear being so straight that it could only have been made by softening the raw material from which it was made and straightening out the curvature. No evidence has yet been produced to suggest which technique might have been involved in this process, and Mr D.J. Rackham has pointed out (personal communication) the crucial nature of the species identification here, since there existed a straight-tusked contemporary of