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Flint Axe Manufacture in the Neolithic: Experiments with Grinding and Polishing of Thin-Butted Flint Axes

by BO MADSEN

This article presents observations made during the experimental polishing of replicas of neolithic flint axes. The investigations are not yet complete, but some preliminary results are described which will later be supplemented by further experiments.

The experiments are part of a project which has been running for several years, concerned with neolithic flint axe manufacture, carried out by Jacques Pelegrin and the author. The preliminary experiments dealing with the flaking process have been described in an earlier number of the Journal (vol. 2, 1983). The polishing experiments took place in 1983 at the Lejre Research Centre in Denmark, which is the sponsor of the project (1).

ASSUMPTIONS AND HYPOTHESES

Societies using simple technology have used ground stone over much of the world at various times, in some places even into the twentieth century. Like other basic lithic techniques, grinding has been developed and used independently in a number of widely separate areas. Ground stone tools, especially axes, have played an important part in the material culture of many semi-agricultural and agricultural societies, and have also been used by a few hunter-gatherer groups.

Many ideas have been put forward about the time involved in the "difficult" grinding process. "The grinding of hard stone is not just a fatiguing process that demands persistence, time and some working knowledge, but a method that gives very little external result in a given time" (Semenov 1964, 68). This author also pointed out that the grinding of a flint axe takes twice as much time as the grinding of a stone (diorite) axe.

The experiments that are described here were carried out to test and add to earlier observations. They were also tests of potential alternatives to the "traditional" method: grinding using great pressure, and involving co-operation between several people. The experiments were designed:

1) to provide a precise measurement of the time budget (in man-hours) involved in the grinding of several replica thin butted axes with proportions and sizes near the average for the originals;
2) to show whether the grinding method had any influence on the type and extent of the striations and polishing;
3) to measure the efficiency of various grinding methods, by recording the weight loss of the axe in grams per man-hour;
4) to measure the effect of grinding on the proportions of the axe (the change from stages 4 to 5).

EARLIER EXPERIMENTS

N. F. B. Sehested, the pioneer of experimental archaeology, carried out and described the first experiments with the grinding of flint axes. The results were published 100 years ago, in a lavish volume (Sehested 1884, 14–21). A number of larger and smaller experiments were described, including the erection of a log house made of timbers shaped with flint tools. Sehested also carried out a total of 6 experiments in the grinding of original flint axes. The most complete is that described as the "Fourth Experiment" (pp. 17–20), in which a thin-butted flint axe, "ready for grinding" and 18 cm long and 6.7 cm wide, was polished. The narrow sides were 2.6 cm broad. Grinding was carried out on a flat piece of granite, 73 cm long and 40–50 cm wide.

On the original axes Sehested had seen three types of grinding: "The coarse grinding, the fine grinding, and the sharpening". Experimental grinding is described on p. 19:

"The coarse grinding was carried out using sharp gravel and water. The gravel was often renewed, because it was quickly crushed into small particles. The axe was moved back and forth lengthwise, pressed down as strongly as the maker was able using two hands.

While the broad faces and the edge areas were being worked, a somewhat rocking movement was imparted to the grinding action – the lengthwise motion being kept up, however – to give the sides and edge areas the rounded form they have, and which the flaking indicates.

During the grinding of the narrow side the same rocking movement was used, but to a much lesser extent, because the narrow sides of the axes are only slightly rounded.

By using the rocking action, one avoids the larger or smaller flat surfaces that would be produced by a more rigid movement.

The edge areas were then ground more finely. It seemed best to use a stone of the same type as the fine old grindstones, sandstone or quartzite, so a fine, flat piece of sandstone was used, which was kept wet.

This grinding was done using movements in all directions, during which the edge area became completely smooth, as on the old axes.

The sharpening of the edge itself was done using a whetstone of slate.

The axe quickly becomes thicker away from the edge, just as the old ones do, which is necessary because of the structure of flint. It is completely smooth as the old axes were, and so sharp that it can be used for all the woodworking tasks involved in the building of the abovementioned log house, and indeed so fine that one could cut ones finger nails with it.«

One of the broad faces was not ground, so that work time was calculated from Sehested's experience from the other surfaces. He calculated that the work would take about 36 hours. "*With this method, a man working for 6 hours per day can grind an axe in less than a week*".

References to grinding, and particularly to the experimental grinding of flint, have since appeared sporadically as short, undocumented notes. Twentieth century experimenters with flint working have carefully avoided grinding experiments, or have used modern grinding methods (Kragh 1964, 39). Descriptions of axe manufacture and grinding in the New Guinea Highlands are, however, important ethnographic sources (Vial 1940, Chappel and Strathern 1966, Højlund 1981).

In connection with the second lithic seminar at the Lejre Research Centre (Wickham-Jones 1982), experimental grinding was once more brought to the attention of archaeologists through some preliminary work. One of the participants, the flint worker Ivan Andersen from Jutland, had already had several years' experience with the grinding of flint axes (2). One of the participating archaeologists has since used his observations in a recent publication (Olausson 1983).

TYPES OF POLISHED FLINT AXE IN THE SOUTH SCANDINAVIAN NEOLITHIC

During the last ten years there have been several studies of neolithic flint axes (Becker 1973, Højlund 1975). The largest piece of work carried out involved the analysis of nearly 1200 pointed butted and thin butted axes, and some 700 thick butted axes (Nielsen 1977, 1979). Ground lenticular stone axes start being used in the south Scandinavian mesolithic during the later Maglemose Culture. The grinding of flint axes was first introduced in the early Funnel Beaker Culture, about 4,000 BC. Ground flint axes were in use for more than 2000 years, until the earliest bronze age. The typological sequence runs from pointed- and thin-butted types to thick-butted axes which come into use shortly before 3000 BC. A selection of the characteristic types is shown in fig. 1. The most frequent are the thin-butted type, particulary types III and VI (Nielsen 1977), which are the longest lived forms (Fig. 1C, 1D).

Thin-butted axes are generally heavy, with convex, rounded cross section, and lenticular section through the long axis. The typologically later form, type VI, has a flatter blade, and has morphological traits pointing forward in time towards the earliest thick-butted forms.

The thick-butted axes are relatively lighter, and have a regular rectangular or square cross-section at the butt end. The edge is narrower and less curved than in thin-butted types.

Grinding of thin-butted axes is generally total, so that both the broad and the narrow surfaces are ground over all. Thick-butted axes are ground only on the broad surfaces, except for many fully ground axes of medium bladed form (Becker 1973, Nielsen 1979). In general terms, Sehested's description of the various types of grinding is widely applicable. But if one takes a closer look at the thin-butted axes, particularly the large ones which may be over 30 cm in length, groups of straight and parallel grinding striations may be seen

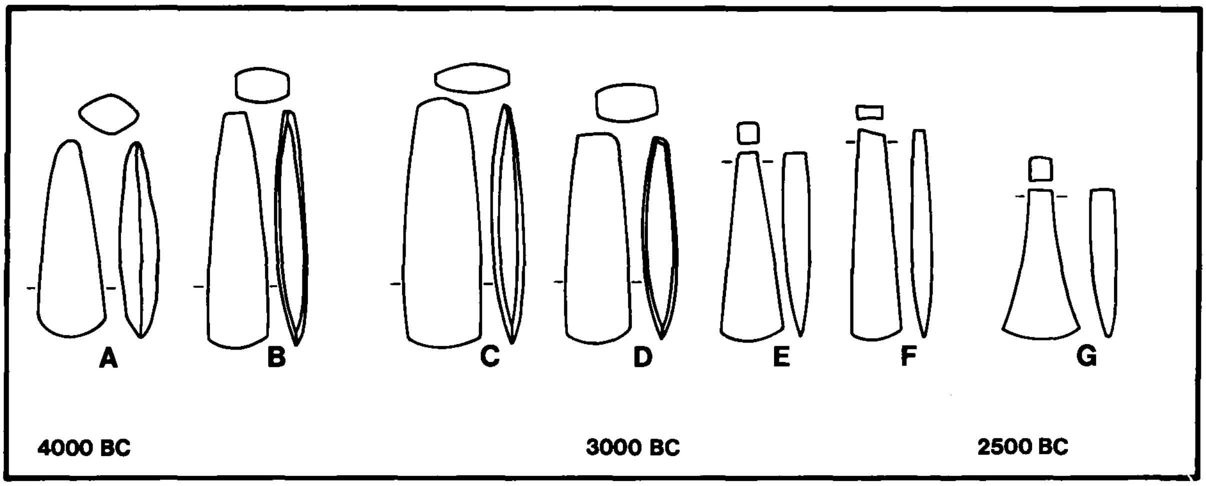

Fig. 1. The axe types of southern Scandinavia: outline of the main types.

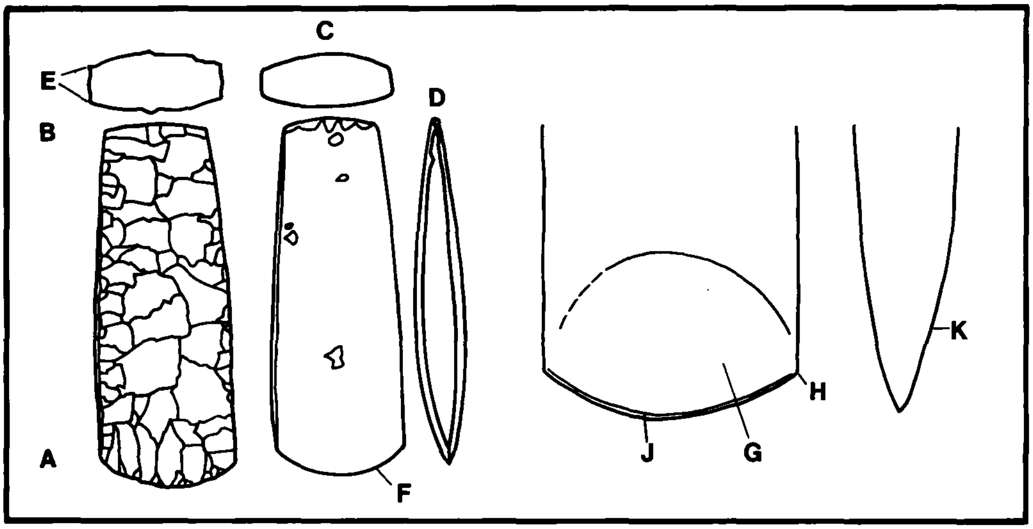

Fig. 2. Some of the qualitative aspects of thin-butted axes. A: edge. B: butt. C: face. D: side. E: seams. F: edge rim. G: edge area. H: edge corner. J: edge facet (sharpening). K: possible grinding facets in the edge area.

which are longer than is usual on other axe types. These axes have often been made relatively flat by straight, longitudinal grinding. The striations are often accompanied by powerful crushing marks at particular points (fig. 13).

TERMINOLOGY

The typological attributes of neolithic flint axes have already been described in detail (Nielsen 1977, 1979). The attributes of interest for the experiments are shown in fig. 2. The edge area (fig. 2B) is regarded as the area stretching from the broad face to the edge rim, being steeper, and marked with one or more grinding facets (fig. 2K); the transition is, however, diffuse.

Grinding is the process which leaves macroscopic traces in the form of striations or crushing spots. This process produces the definitive shape of the axe through removal of material.

Polishing is a process which does not leave macroscopic striations, but primarily changes the micro-

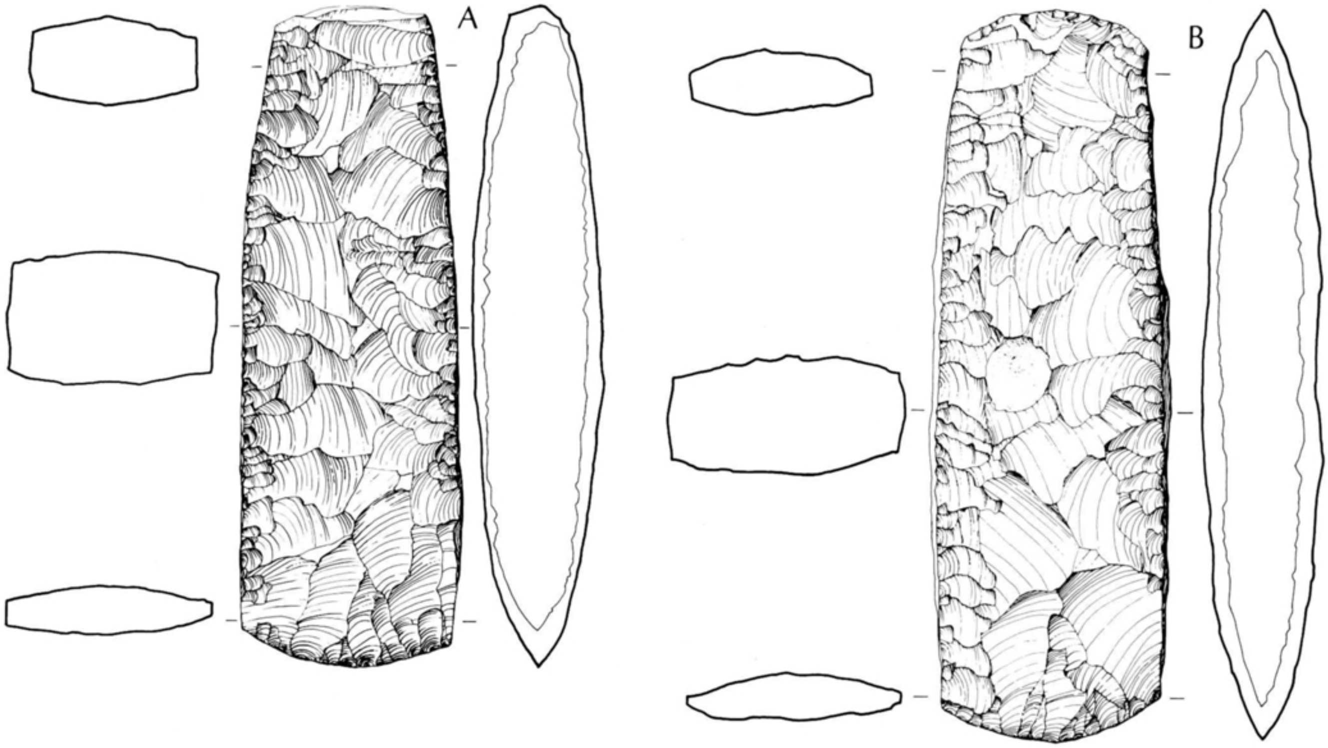

Fig. 3. A: the axe ground in experiment I. B: the axe ground in experiment II. BM *del.* 2:5.

scopic nature of the surface. Liquid film does not change the lustre of the flint after this process.

EXPERIMENTAL PROCEDURE

The production of a thin-butted ground axe involves three different activities: procurement of the raw material, flaking to shape, and grinding. The flaking falls into 4 stages (Hansen and Madsen 1983, Madsen 1984).

All the grinding experiments were done on a piece of Nexø sandstone 110 cm long, 75 cm broad and about 10 cm thick. With regard to many neolithic grindstones, this piece must be described as medium hard, perceptibly grained, and without concoidal fracture.

The most regular of the two cloven surfaces was used so that grinding took place along its longest axis (fig. 7). During the experiments, the grindstone was placed horizontally on some treestumps, in a firm position 60 cm above the ground. The experiments took place on a lake shore in the shade of an oak tree.

Even during the first experiment, a cigar-shaped grinding groove was produced, about 80 cm in length. During later experiments it became necessary to start on a parallel groove. Various positions were adopted during the longitudinal grinding of the axes. When the faces were ground, the axes were often rotated, so that grinding extended out over the seams (fig. 2E, fig. 5). During grinding of the butt area and particularly of the edge area, the axes were held at various acute angles to the grindstone. A rocking motion was often used in this longitudinal grinding.

During the grinding of the edge area, the axes were sometimes moved slightly diagonally in relation to the grinding groove, to attain maximum contact with the grindstone. The intention was not to produce a flatly ground surface, but to grind the axes all over following their rounded convex shape. Three methods were employed during the experimental grinding:

Area grinding: a smaller grindstone was hand-held and used on the axe, or vice versa. Careful strokes a few cm long were used. This was used to round off the seams and edge, and to complete the sharpening of the edge.

Hand grinding: The axe was held in both hands, and rubbed against the grindstone by one person, using regular controlled movements. The strokes were either

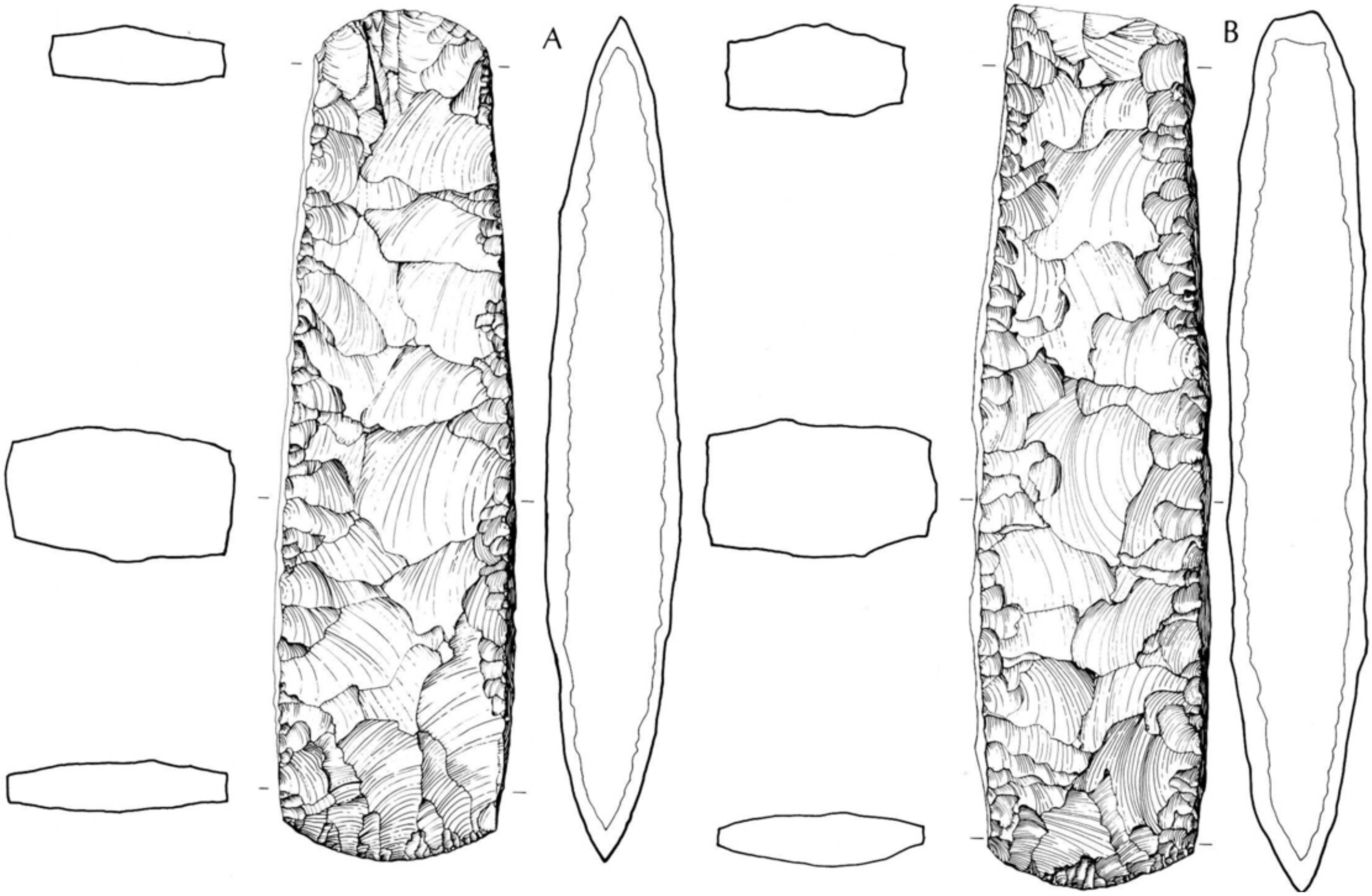

Fig. 4. A: the axe ground in experiment III. B: the axe ground in experiment IV. BM *del.* 2:5.

long and powerful (15–25 kg), or short, light and precise, 10–15 cm in length (during edge grinding). During this heavy manual grinding, the weight and strength of the body was only used when the axe was pushed forwards. When the axe was pulled back, it only rested lightly on the grindstone. The movement and the standing position are analogous to those of a carpenter, planing a piece of wood on a workbench. During axe grinding, the position is more bent, and the motion slower and heavier.

Grinding with extra weight: In this method the axe is held in a vice, which increases the pressure on the axe. This "system" is based on "the principle of least cost", using a technology known in the neolithic. The vice consists of a branch of ash about 4 m long and 15 cm in diameter, partially split so that the axe is held in position by the tension of the wood. The branch is easily split with a couple of wooden wedges, the axe is placed in position, the wedges are removed, and the axe is held firmly in position.

Vertically above the vice is placed a forked branch (fig. 6). Each fork rests in a hollow on top of the vice. On top of the fork is a heavy piece of flat sandstone. This creates a balanced but heavy weight applying the greatest possible pressure to the axe, without the 80 cm grinding motion being disturbed.

During experiment II and part of experiment III, the whole system was used to apply a total of 80.5 kg to the axe. For practical reasons this was later reduced to 52 kg. To operate the system takes *three people*. One person holds each end of the vice, alternately pulling and pushing. The third person was in the centre, helping with the movement and also checking the exact position of the axe on the grindstone.

For grinding those areas where excessive pressure could cause damage (the sides, seams and edge areas), the split branch alone is used, which applied a pressure of 32 kg to the axe. In these cases the system was operated by *two people*.

During the experiment, no grinding agent like sand or gravel was used, except for a short time during experiment II. Water was, however, freely used to wash away the fine fragments produced during grinding. The basic grinding strategy was:

1) Rounding off the sharp seams and edge corners by area grinding, and rounding off the sharp, bifacially flaked edge by transverse area grinding. This makes the edge slightly flattened (fig. 9B), a precondition for its final sharpening.

2) Grinding the faces and sides of the axe.

3) Grinding the edge area.

4) Sharpening the edge by establishing a slight edge facet (fig. 2J). This is done with diagonal and/or transverse area grinding using finer sandstone or slate. This grinding is so fine that it cannot really be distinguished from polishing.

A detailed log book was kept for all the experiments (3). In this was recorded the net grinding time in terms of how long the axe was moved on the grindstone. Also recorded was the total work time, including pauses and adjustments. In practice, 100 grinding strokes were carried out at a time. The length of the utilised grinding surface was carefully recorded. For experiments I and II, the gradual expansion of the ground area on the axe was recorded at the short interval of every 400 strokes (fig. 8). All axe replicas were precisely measured and weighed before and after grinding (4). The axe replicas' sides were numbered, so that the extent and type of grinding could be recorded for each side.

Four experiments will be briefly described below. The quantitative data are tabulated in fig. 10.

EXPERIMENT I – HAND GRINDING

A replica thin-butted axe of type VI was chosen for this experiment, made by JP from medium to good quality flint from Falster. This quality of Senonian flint has a black to bluish grey colour. The flaked axe must be described as most regular, with beautifully worked seams and edge, although the cross-section twists slightly in relation to the medial plane.

The axe was relatively thick and short, with a weight of 1174.4 g, a length of 22 cm and a thickness of about 4.5 cm (fig. 3A). Only the faces of the axe were ground, in the outer part of the edge area, and it has still not been finally sharpened. The axe was ground while the grindstone was still uneven and before grinding grooves had developed. There were 11,800 grinding strokes in all, mainly around 50–60 cm in length; for some periods, however, stroke length was 70 cm, and the edge area was ground with short strokes of 15–25 cm. In all, the axe moved 6650 m on the grindstone, over a period of 5 hours and 30 minutes (table 10). The sharpening (which was not carried out) would have taken an estimated 15 to 25 minutes. The ground surfaces showed light to medium grinding striations. Slight facets could be made out along the seams, and one face (side 3) showed a grinding facet in the edge area (fig. 12). The grinding removed about 0.3 cm from the maximum thickness.

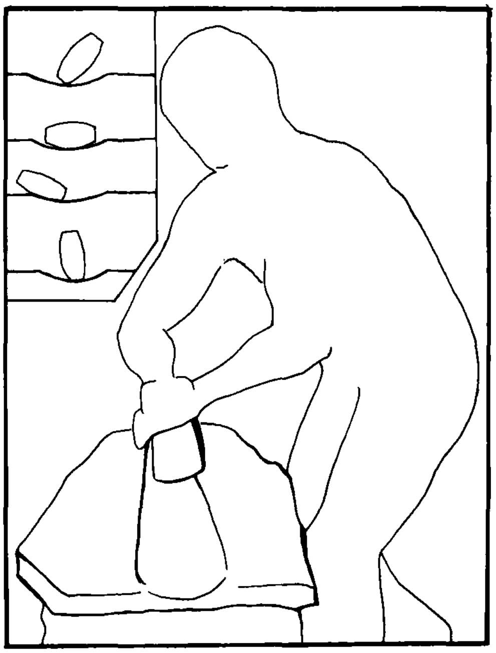
Fig. 5. Hand grinding.

EXPERIMENT II – GRINDING WITH EXTRA WEIGHT

A thin butted axe replica of type III A (fig. 1C) was used, made by BM from medium quality Senonian flint from the coast of Djursland, eastern Jutland. The typical axe had very regular lines with medium fine seams, which were, as with all the replicas, shaped with the "turned edge" method. During the flaking of side 3, two hinge fractures occurred in an attempt to make the angle of the edge sharper. The axe was relatively broad and flat, with a weight of 1127.2 g, a length of 24 cm, a breadth of 8 cm and a thickness of 4.1 cm (fig. 3B).

All four surfaces were ground. The two narrow sides were done first, with a combination of hand grinding and grinding with extra weight (32 kg) with the axe fixed in the split ash branch. This was carried out quickly, the sides taking 30 and 21 minutes.

In this work the grinding groove was unintentionally deepened. (This could have been prevented if the grinding had been spread out more across the groove.) It was therefore necessary to establish a new grinding groove.

As mentioned earlier, sand was used for a short period (8 minutes) during this experiment. This was not intended as a grinding agent, but to stabilise the movements of the axe on the still uneven surface of the grindstone.

After the seams, edge corners and edge rim were ground with area grinding and hand grinding respectively, the faces were ground with extended use of the maximum weight of 80.5 kg. The friction was so great that during the grinding of face 3 it was noted in the log book that the axe was warmer than blood heat! Length of grinding stroke was 80 cm. The axe moved a total of 6810 m over the grindstone, taking 10,600 strokes in 4 hours 30 minutes, and was by then fully ground as far as the outer edge area on side 3 (fig. 14).

On all four surfaces, powerful, long and parallel striations were visible, which partially ran over into the most powerful type of grinding trace: crush marks at certain

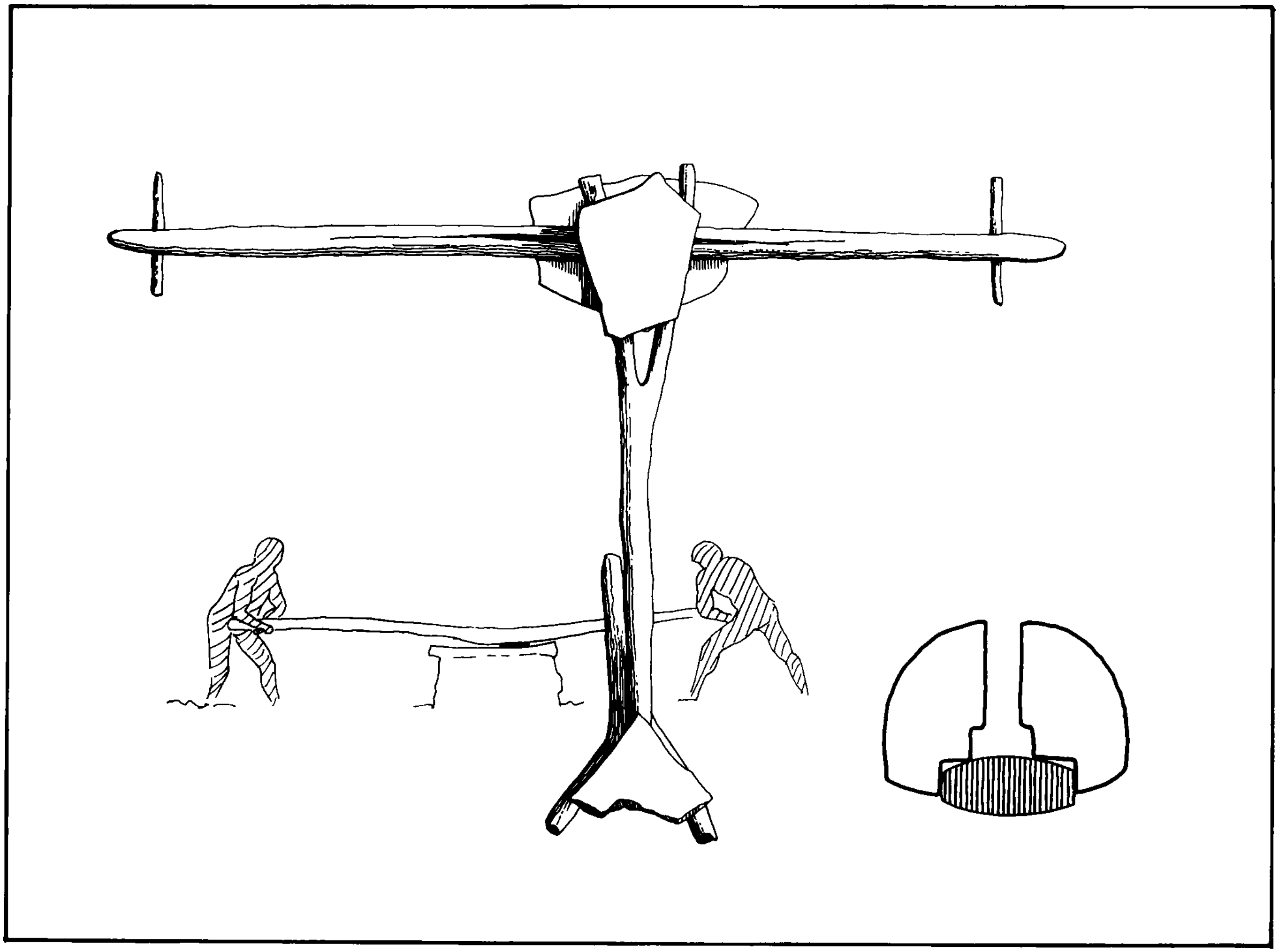

Fig. 6. The system used for grinding with extra weight. BM *del.*

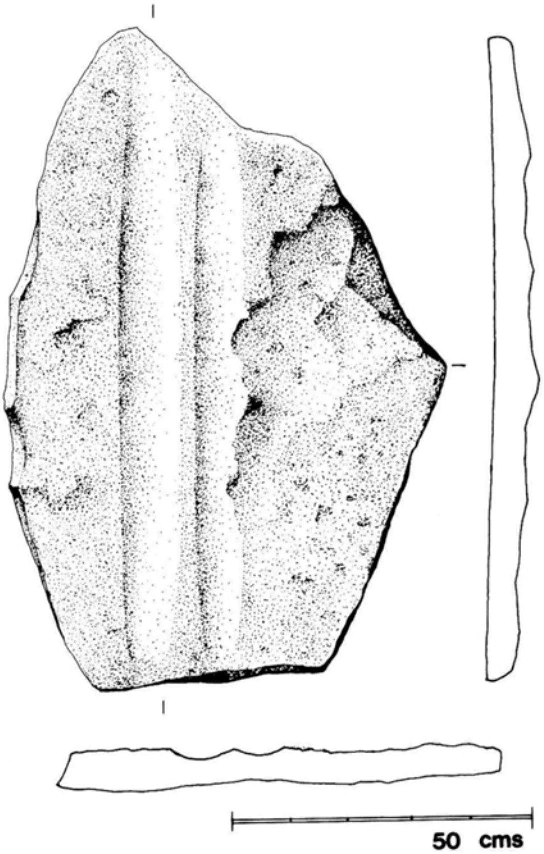

Fig. 7. The experimental grindstone. BM *del.*

points. Clear grinding facets occurred in both edge areas (fig. 2K). Grinding reduced the maximum width by 0.35 cm, and the maximum thickness by 0.77 cm.

EXPERIMENT III – GRINDING WITH EXTRA WEIGHT

A thin-butted axe of type III was ground, made by JP from light greyish blue Senonian flint from Falster. This variety was decidedly porous. The large replica was of typical shape. It was the most regularly flaked of those used in the experiments, regarding both surface working and cross-section through the long axis and general outline. The edge area was perfectly flaked. This axe blade was slightly twisted, as are many original thin-butted axes. Length was 29.2 cm, greatest breadth 8.3 cm and greatest thickness 4.7 cm (fig. 4A). It weighed 1671 g.

This axe was the most completely ground of all the experimental examples. The edge was so well ground that light transverse sharpening for 5 to 10 minutes was all that was necessary. Edge grinding was done on the large grindstone, which now had a smooth, suitable grinding groove. A rounding of the sharp edge (fig. 9B) by area grinding meant that hand grinding could be taken right out to the edge without risk of damage – a wellknown technique in lapidary technology (Scarfe 1970).

The heavy grinding was carried out as described for experiment II, except that the maximum weight of 80.5 kg was reduced to 52 kg during experiment III. This led to better control over the movement of the axe in the groove. The axe travelled a total of 12,340 m in 16,350 grinding strokes, in a time of 6 hours 38 minutes. There was a grinding facet in the edge area on side 1, which also had powerful striations and crush marks similar to those noted in experiment II. Greatest breadth was reduced by 0.4 cm, greatest thickness by 0.5 cm.

EXPERIMENT IV – GRINDING WITH EXTRA WEIGHT

The last axe to be polished in this series of experiments was a large thin-butted replica of type V, made by BM from plain, dark Senonian flint of the best quality from Falster. The axe had lines typical of a piece of lesser quality. Surface flaking was irregular, with several concave hinge fractures, which would need much grinding down. Length was 30.3 cm, greatest breadth was 8.3 cm and greatest thickness was 4.8 cm (fig. 4B). The axe weighed 2013.4 g.

Grinding followed the same procedure as in experiments II and III. Maximum extra weight was 52 kg. With this weight, grinding was carried out from the faces out over the seams. This resulted in partial pressure damage along these in the form of negative flake scars 0.5 – 2 mm in size, with a truncated form as seen in the so-called "split cone" fracture. The axe travelled 15,830 m over the grindstone, taking 21,650 strokes over 9 hours. The edge was not sharpened. Grinding striations and crush marks were marked on all surfaces. Maximum width and thickness were both reduced by 0.4 cm.

EXPERIMENTAL RESULTS AND OBSERVATIONS

Work time. In the table (fig. 10), net grinding times are given, varying from 4.5 to 9 hours. These are expressed as the number of man hours taken in the four experi-

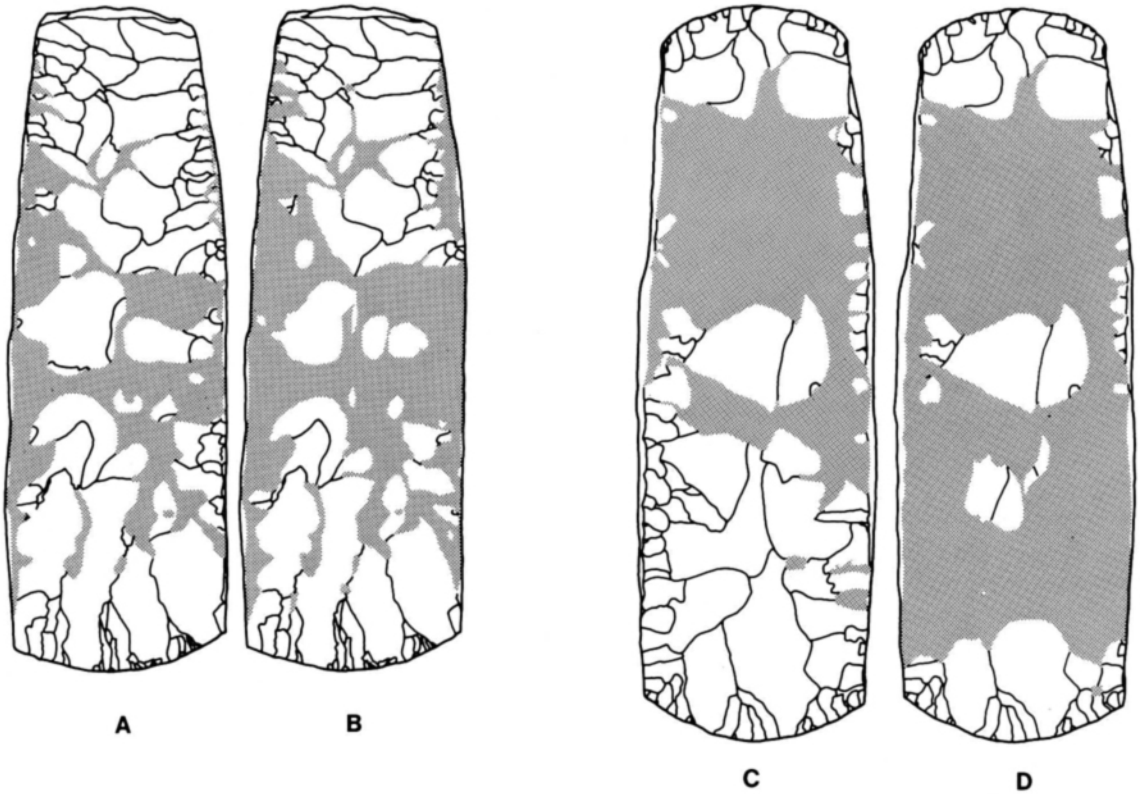

Fig. 8. The extension of ground areas.
Experiment I, side 1: A. After 400 grinding strokes (200 m).
B. After 800 grinding strokes (400 m).
Experiment II, side 1: C. After 400 grinding strokes (300 m).
D. After 800 grinding strokes (600 m).

ments. Anyone who has tried polishing a flint axe must agree that it is monotonous physical labour, which cannot be carried out non-stop. During the experiments, the ratio between net grinding time and total work time varied from 2:3 to 1:3, when the work was slowest. The ratios, which show the practical side of grinding, are to some extent a factor of the workers' physical condition and weight, but are also strongly conditioned by experience, skill and work rhythm. But even if a realistic estimate is 1:2, it still means that a medium sized thin-butted axe can be ground in one day's work.

Earlier experiments have related the total ground area to the time taken to produce it. Sehested gives 0.1 to 0.12 cm^2 per minute. Andersen (Olausson 1983, 32) seems to be able to grind about 2 cm^2 per minute. (For the experiments described here, such a calculation gives from 0.5 to 10 cm^2 per minute). This method of presentation is entirely subjective, however. Fig. 8 clearly shows that increased friction (experiment II) drastically increases the area ground per unit of time.

Weight loss. The above quote from Semenov is contradicted by the experiments, which show that quite a lot of weight can be lost during grinding – from 6% to 15% of the unground weight of the axe in stage 4 of its manufacture. In experiment IV, about 300 g flint was removed in grinding. This corresponds to the weight of a small flint axe. It can be added that use of extra weight and several people made the grinding more economical in terms of time and energy. The figures in the table (fig. 10) show that there seems to be a weightloss increase of several grams per man-hour if extra weight is used.

Quality of flaking. The surface topography of the axe is clearly of great importance. A comparison between experiments III and IV is a useful example of this. It took 9 man-hours more to grind the axe with the worst flaking. One of the conclusions from experiment IV was that it would be easier to rough out a new axe (which takes about 2 hours) than to grind for a whole extra day

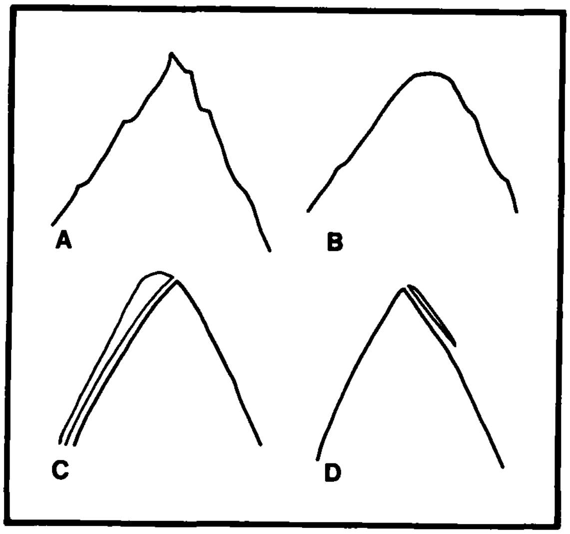

Fig. 9. Grinding of edge rim and edge area. A: the sharp, bifacially flaked edge before grinding. B: rounding off the edge. C: grinding the edge area on both faces. D: sharpening the edge rim. Grethe Rasmussen *del.*

– always assuming there is plenty of available flint.

The axe ground in experiment III had the greatest weight loss relatively to working time. Several factors were probably at work here, which two possible ones are: the axe was made from porous flint, which may have been easier to grind; more important, however, is the fact that a well-flaked axe, with close and regular spacing of the negative flake scars and characterised by many small projections and many facets, can be ground quicker than a more crudely worked axe. A crude axe has larger projections and fewer facets. During grinding, crumbling or crushing of the sharp points of the projections is constantly taking place, and it seems that larger fragments of flint are broken off with conical fractures. This process increases the amount of flint removed by the sharp grains in the grindstone.

Type consistency. Measuring the diminishing of the axe sizes showed that, although there was a clear drop in thickness, and to some degree of width and length, the grinding process did not affect the typological traits of the axe. It is, therefore, justifiable to use the same type descriptions for both ground and unground prehistoric axes – so long as one makes the same reservations as Becker (1973), who presents detailed examples of reworking of ground thin-butted axes. This seems to involve repairs to thin-butted axes damaged during use (Becker 1973, figs. 10 and 11). There is also one example of an axe altered entirely by grinding, from a thin-butted axe to a hollow-ground adze (Becker 1973 fig. 16). A partial reworking of a ground stone axe which still preserves the original type (as described by Becker), is, however, not possible (Becker 1973, 133). The illustrated examples of these are in fact unfinished thin-butted axes, with greater or lesser partial grinding (Becker 1973 figs. 8 and 9).

Macrostriations. One of the aims is to examine whether there is a connection between grinding method and appearance (nature and extent of striations and polishing). Figures 11A and 11B show photographs of side-lit silicon rubber impressions of the ground faces of two different axes (5), from experiment III (grinding with extra weight) and experiment I (hand grinding) respectively. The striations in fig. 11A are clear, deep and parallel. They are also longer than in fig. 11B, and are accompanied by areas of crush marks, which are irregular and pit-like. The surface of fig. 11B has more transverse striations, fewer crush marks and much greater areas of of polishing. These striations, formed by grinding on the quartz sandstone, are very similar to the striation type illustrated by Meeks, Sieveking, Tite and Cook (1982, 327). Figs. 13 and 14 compare an early neolithic axe of type IV, ground all over, with one of the experimentally ground axes from experiment II. The hypothetical connection between grinding method and appearance seems at present to be quite likely correct; more investigations must be carried out, however, to provide more thorough documentation and quantification.

Traces of use. Becker (1973, 130) mentions the difficulties in distinguishing these from deliberate polishing. The experiments confirm that this is the case. Polishing resembling gloss appeared in the edge area itself, even though considerable pressure was used in grinding.

If use traces are to be demonstrated, they must be in the form of microscopic polishing from wood in the edge area, not arbitrary polishings or macrodamage like the small "feather terminated scars" illustrated by Olausson (1983, fig. 25).

EXPERIMENT No.	I	II	III	IV
3 men at work pressure 80,5 kgs	-	1^h 48' 50"	63'	5^h 22'
3 men at work pressure 52 kgs	-	-	58'	-
2 men at work pressure 32 kgs	-	1^h 34' 55"	1^h 28'	1^h 46'
1 man at work "handgrinding"	5^h 31' 25"	1^h 3' 35"	3^h 9' 30"	1^h 48'
Total net time	5^h 31' 25"	4^h 27' 20"	6^h 38' 30"	8^h 56'
No of grinding strokes	11800	10600	16350	21650
Meters	6650	6810	12340	15830
Weight reduction	74,5 g	147,3 g	197,0 g	300,1 g
Man/hours	5,5236	9,6666	12,1417	21,4333
Grs. removed per man/hour	13,4875	15,2389	16,2250	14,0015

Fig. 10. Quantitative data from the experiments.

COMPARISON WITH OTHER GRINDING EXPERIMENTS

A comparison of the experiments at Lejre in 1983 with those of Sehested calls for some comment on the long grinding time used in 1881. This long time can be explained by the fact that Sehested used granite as a grindstone and added gravel as a grinding agent. Compared to sandstone and water, this method produces far less friction, creating a sort of ball-bearing effect. Furthermore, we know nothing of the quality of the flaking of the axe Sehested used. Finally, it is likely that Sehested's times are inclusive of a number of rests. The Lejre experiments agree much more closely with the experimental grinding of 3 flint axes described by Olausson (1983, 23). One thin-butted and two thick-butted axes were ground by Ivan Andersen in 2 hours 5 minutes, 4 hours 5 minutes and 4 hours 10 minutes respectively. The edge area of the thin-butted axe was ground on carborundum for 20 minutes, the rest of the grinding being on sandstone. Grinding time for the thin-butted axe seems very short. Th explanation is, to judge from the illustration, that the axe is not fully ground.

AXE GRINDING IN NEW GUINEA

Stone axes were manufactured in several regions of east new Guinea until the 1940's (Vial 1940). Mining, flaking into shape and grinding are all described. The raw material was layered, siliceous slate or more uniform rock types, characterised by partial or complete conchoidal breaks. The three types manufactured were working axes with lenticular and rectangular cross sections, and large, thick axes for bridewealth, together with ceremonial axes, which were the best prepared. The last named have flat, rectangular cross-sections, and the blades are ground all over and are up to 30 cm in length. These ceremonial axes are not without a certain similarity to our own medium bladed, thick-butted axes (Becker 1973, fig. 27) and axes of late neolithic type (fig. 1G).

In the 1960's the original character of the axe production in the Highlands was replaced by the manufacture of axes from softer stone, used among other things to sell to the tourists (Chappel and Strathern 1966). Originally the axes were bifacially flaked by direct percussion, using an ovoidal hammer stone. The thick, lenti-

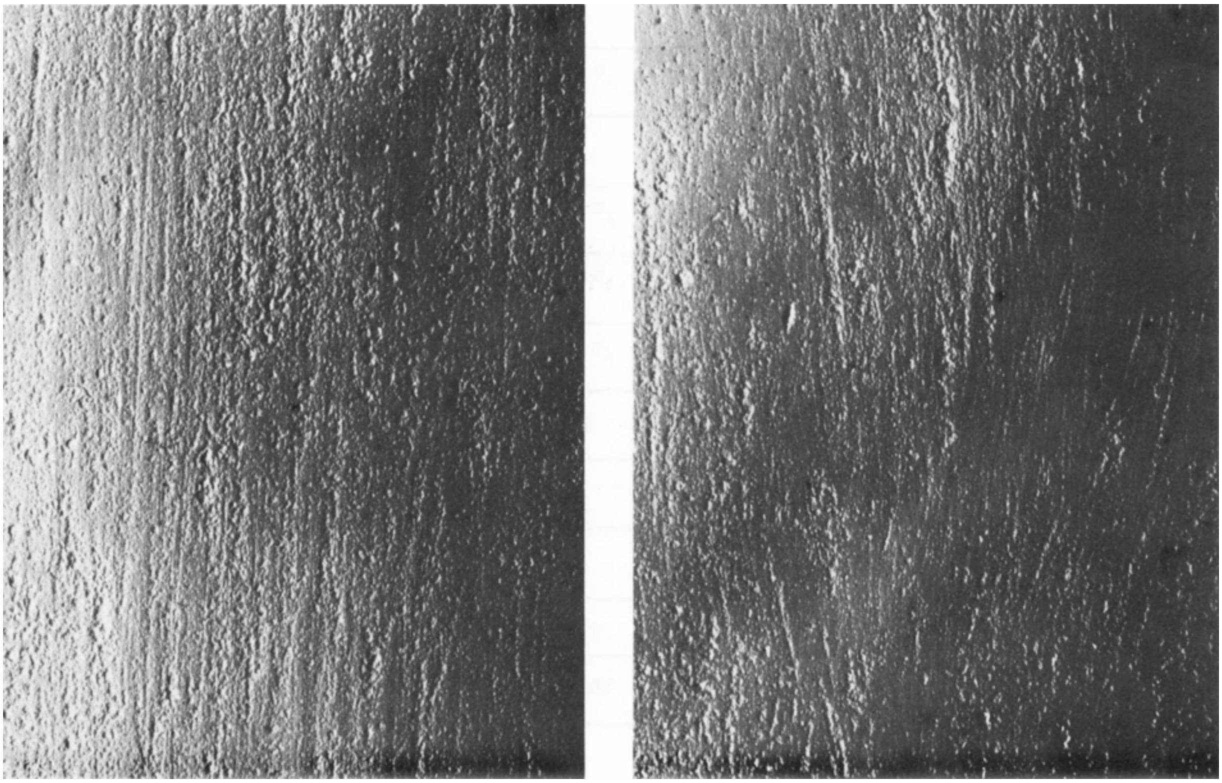

Fig. 11. Silicon rubber impressions of traces of grinding, lit from the side, taken with an Optica reprocamera. The dark shadows are due to the concave surface of the impression. A: Experiment III, side 3. B: Experiment I, side 1. Photo: E. Benner Larsen. 2,2:1.

cular cross-section was squared off by grinding – a process demanding a lot of grinding.

Vial (1940, 160) states that it took about three days to grind a ceremonial axe, and gives the following description of the work (see also Højlund 1979, 35):

"All the villages and hamlets have their polishing 'factories', the essentials of which are water and blocks of sandstone and a shady place to sit. Sometimes men worked by themselves beside a hole in the ground filled with rain water, sometimes six or eight men worked side by side on the banks of a small stream. Two races were noticed in the forest between villages, and the local natives with us said these carried water for axe polishing.

A number of men were seen at work polishing blades. The man sat beside his water-supply with blocks of sandstone propped up on the ground before him, and dipping the stone blank in the water, held it in both hands and rubbed it backwards and forwards on the sandstone, stopping now and then to examine it and wet it again. In addition to the large pieces of sandstone there were some smaller pieces lying nearby which were apparently used for the final touches, though I did not see this.«

In northeast Irian Jaya (west New Guinea) stone axes are still being produced. The work involves flaking with direct percussion using a hammerstone, pecking and grinding on quartzite using water, and finally polishing on palm leaves containing silicon. A French gemologist visited the village of Ormu Wari in 1982, where axes are made for the other villages around Lake Sentani (Gonthier 1982). These axes, which are polished "as smooth as water", are used according to the author for ceremonies and bridewealth.

DISCUSSION

We now see examples of modern flint workers being used as informants. The observing archaeologist can find himself in a situation almost parallel that of travellers in the early days of ethnography, who received almost whatever answers they wanted from the friendly informant (Olausson 1983, 34).

Fig. 12. The experimentally ground axes.

In this work, Olausson undertakes an examination of raw material availability, production process and use of flint and stone axes in the neolithic of Scania. Basing her comments on the comments of the informant, she argues that flint axe manufacture was an unspecialised task, which could be learnt by most people very quickly. Olausson believes that at least one member of each family would have been able to manufacture flint axes.

When Strathern inquired about the grinding of ceremonial axes at Maegmul in the New Guinea Highlands in the 1960's, he was told that the work took a good three weeks. This was very different from the account of Patrol Officer Vial from 25 years earlier (Chappel and Strathern 1966, 98). The flaking process could still be demonstrated with the help of a steel axe, but at Maegmul people were no longer acquainted with the details of the grinding process.

In neither the ethnographic nor the experimental archaeological situation can observations about material culture be made without understanding the informant's background. Olausson's informant (6) is beyond any doubt very skilful at producing four-sided flint axes with a copper fabricator. But the fact that he taught himself this in a short time is no justification for extrapolations to be made about the entire neolithic axe production of Scania. It can be stated with at least

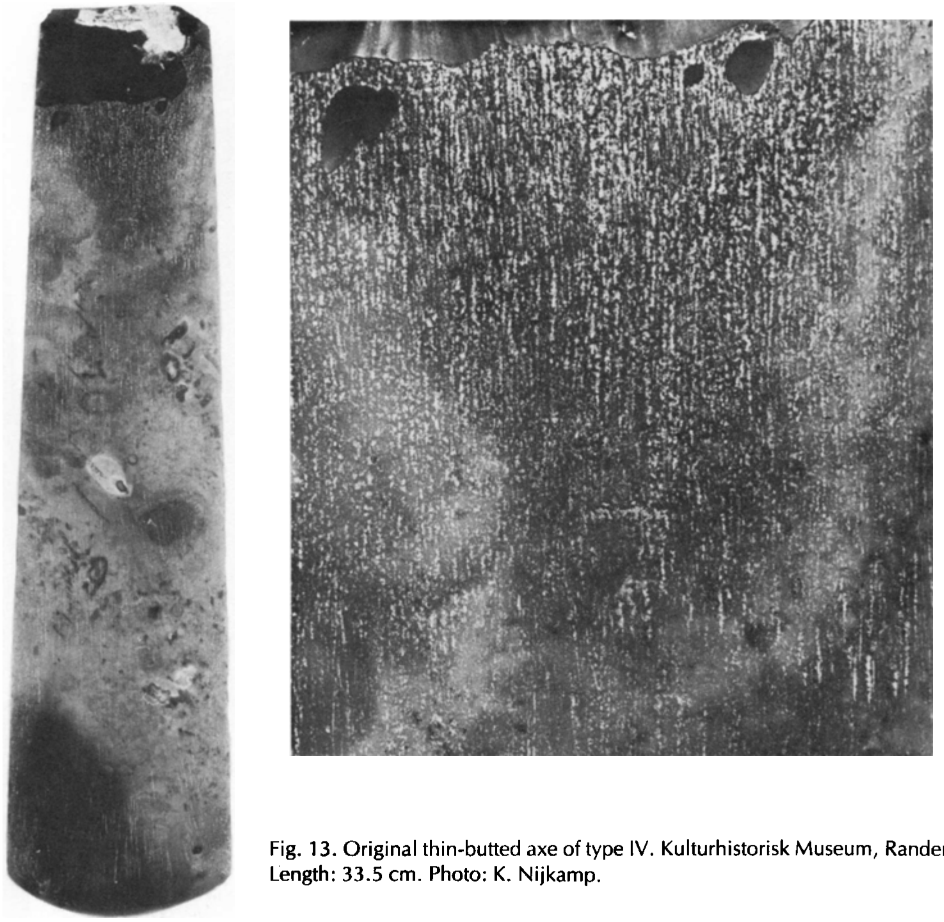

Fig. 13. Original thin-butted axe of type IV. Kulturhistorisk Museum, Randers, no. 1662. Length: 33.5 cm. Photo: K. Nijkamp.

as much force that the experimental results, arrived at through flaking at a replicative level, show that the flaking of four-sided axes with antler fabricators is a process which takes several years to learn. Merely to maintain that the second stage of axe manufacture, the shaping of a four-sided flint blank by direct percussion, can easily be learnt by anyone, would correspond to a claim that the middle palaeolithic Levallois flaking system was straightforward.

There appear to be no great differences between the experimental results and the descriptions from New Guinea, either as regards grinding methods or the time involved. In New Guinea it is clear that stone axes are exchanged and utilised in areas far beyond the place of manufacture. The distributions of some axe types of the south Scandinavian neolithic are also much greater than the areas where production took place. The flaking into shape of these flint axes is regarded as work that from a regional perspective would be collectively specialised. Flaking was carried out by groups in the areas most rich in the raw material (Hansen and Madsen 1983). As in New Guinea, local production of axes with inferior flaking would also have taken place in areas poor in raw materials. The range of axes from the Jutland Single Grave Culture includes many types with badly executed flaking (in the coarser Danian flint), and also well flaked uniform axes made of better flint, not of local origin. This shows that it was the completed object, not the raw material, that was traded.

As regards grinding, it seems likely that all users would have been able to grind an axe already flaked to shape, or to sharpen one. The question is whether the grinding process went through a technological development at any time in the early neolithic. One can envisage that better grinding methods might have been used by the specialist groups who shaped and distribut-

Fig. 14. Replica of thin-butted axe of type III. Experiment II. Length: 24 cm. Photo: K. Nijkamp.

ed the axes. In the archaeological material there is a geographical agreement between areas rich in flint, areas with evidence of production (workshops, flint pits and mines, blank production), and concentrations of the longest and most completely ground axes, such as type IV (Nielsen 1977, fig. 16A).

How these hypothetical grinding systems were actually carried out is an unanswered question. The "system" used at Lejre in 1983 was only one imaginative possibility out of many, and should be followed up by further experiments, for example using a method of grinding with extra weight which can be operated by a single person.

Experimental archaeology attains results through the interplay between experience and experiment, and in this way moves from the possible towards the plausible – although often slowly. The researching of lithic technology is still characterised by single experiments, or series of very few experiments. It is hoped that the experiments described here will help to reduce this lack.

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NOTES

1. Thanks are due to Hans Ole Hansen (Director) and Dorthe Hubert Nielsen (Area Administrator), of the Historical-Archaeological Research Centre, Lejre, for all their assistance. Thanks also to Martin Appelt and Simon Drost who added both finesse and strength to the closing stage of the experiments. Peter Kelterborn of Switzerland took part in some of the experiments; thanks to him for his constructive energy, enthusiastic participation and sound advice.
2. Ivan Andersen has worked for several years on the hand grinding of flint axes made by himself (with an iron fabricator). He has con-

vincingly reconstructed the grinding process, works in a standing position and grinds on quartz sandstone. Andersen describes among other things grinding a 420 g thin-butted axe in 5 hours 15 minutes – information from a privately printed manuscript 1981 (Olausson 1983, 32).

3. In connection with the log book, some of the experiments were recorded on video by the Lejre Centre's media workshop. (Malling, O. and Madsen, B. 1983: Experimental Grinding of Neolithic Flint Axes).
4. Thanks to B. Skytte Jensen and P. Boe, of the Chemical Laboratory, Risø Nuclear Research Station, for their willing help and interest.
5. This documentation and analysis was carried out by E. Benner Larsen of the School of Conservation in Copenhagen. The work is part of a project examining tool marks on prehistoric tools.
6. Thor Bjørn Petersen made the axes. It is the experience of the author that most present-day flint workers have been influenced by others. Petersen's methods imitate those of the German flint worker Harm Paulsen, who however only uses antler (Olausson 1983, figs. 5 and 6).

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