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Making fire in the Stone Age: flint and pyrite

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Abstract

Flint implements with rounded ends, excavated at several Late Palaeolithic sites in Denmark and the Netherlands, are described and interpreted as strike-a-lights used in combination with pyrites. Experiments were carried out; the use-wear traces on the experimental pieces are similar to those occurring on the prehistoric specimens. It is concluded that the pyrite technique for fire production most probably predated wood-on-wood techniques, both in Europe and Greenland.

Introduction

The sociologist J. Goudsblom (1992) has drawn attention to the fact that of the main attributes of 'civilisation', viz. tool-use, language and control of fire, only one is exclusively human: control of fire. Already Charles Darwin (1871) stated in his *Descent of Man* that the ability to produce fire 'probably' was the greatest human invention ever, excepting language. Quite a few publications discussing the use and production of fire in prehistoric and historical times have appeared (a few important ones are: Hough 1890, 1926; Harrison 1958 (1954); Oakley 1955, and Perlès, 1977; Collina-Girard 1998).

Archaeological evidence points to an increasing importance of the hearth in the daily life of small groups of people since at least the beginning of the Late Palaeolithic, some 50,000 years ago. The hearth not only attracted many activities for which fire or heat was needed (cooking, technical tasks), but also played an important role in social life. The evolution of a simple language into a complex one, involving abstract concepts, may partly have been driven by daily gatherings around the fire, where stories were told and rituals performed. Group activities associated with the hearth may also have stimulated the development of the arts. Distinct hearths are known from about 300,000 years ago, but the characteristic pattern consisting of dense clusters of artefacts and tools around hearths, as observed at Late Palaeolithic sites (see, e.g., Olive & Taborin 1989; Stapert 1992), seems to be largely absent in older periods.

When studying material from Late Palaeolithic sites in the Netherlands, Denmark and Germany (dating to the Weichselian Late Glacial), we noted 'tools' of a special type, which had hardly been noticed before. These are flint implements with a markedly rounded end (sometimes two), indicating use on some type of hard material. These tools strongly reminded us of similar objects from the Neolithic and Bronze Age. At many sites from these periods, particularly in graves, such rounded flint artefacts were found, often together with pyrite nodules. An early published example is a pyrite nodule with a shallow groove accompanied by a 'long round-ended flake of flint', found 'between the knees and the head' in a barrow near Rudstone in England (Evans 1872, p. 284). Ethnographical sources indicate that flint and pyrite were used in historical times in combination to produce fire. Therefore, the rounded implements from the Neolithic and Bronze Age have been interpreted as strike-a-lights by John Evans and many other authors (among them Sarauw, 1907).

In the present contribution, we suggest that at least some of the rounded flint tools from the Late Palaeolithic were used in the same way (cf. Johansen & Stapert 1995, 1996). Rounding of flint implements may also result from other types of use, however; for example, from boring or engraving in stone or other material. We carried out a series of experiments with flint tools, using them to engrave and bore into several types of material. For this work, which was carried out in 1995 at the Archaeological-Historical Experimental Centre at Lejre (Denmark), we employed experimental flint tools on pyrite, hard and soft limestone, slate, sandstone, quartzite and hide. The resulting wear on the tools was then examined under a stereomicroscope with an attached camera, using magnifications up to 50x. The flint implements used as strike-a-lights revealed a characteristic pattern of use wear traces, consisting of dense sets of subparallel striations in addition to gloss and rounding; often some micro-splintering was visible as well. We found the same pattern on several rounded flint tools of Neolithic and Bronze Age. The use-wear produced on flint tools by other tasks performed at the Lejre Centre looked different, and we therefore believe that it is possible in most cases to identify flint implements used for making fire with pyrite.

We proceed in the present contribution from subrecent times to periods further back in time. First, ethnographical data are briefly reviewed. In historical times, two techniques of fire production were in use: friction of wood on wood and percussion of stone on stone. Selected examples of fire-making equipment from the Neolithic and the Bronze Age in Europe are described. During these periods, fire was probably produced mainly (or even exclusively) by one single method: the flint/pyrite method. It is likely that the same is true for the Mesolithic. The core of the present contribution concerns evidence for the use of the flint/pyrite technique during the Late Palaeolithic in Europe; several flint implements interpreted by us as strike-a-lights from this period are presented. Some results of experimental work that seem to support this hypothesis are briefly described. We then turn to ethnographical and archaeological evidence from Greenland. Finally, at the end of the contribution, we will discuss briefly the probable evolution of fire-making techniques.

Two ways of making fire

It can be deduced from the rich ethnographical literature on the subject that there are two basic ways to produce fire, both with many variations: the first by friction of wood on wood, and the second by percussion or friction of stone on stone (a few important sources, among many, are: Collina-Girard 1998, Hough, 1890; Birket-Smith 1929). Whichever of these techniques is used, the produced sparks are caught in material that will easily smoulder. Though many materials are suitable for the purpose (finely pounded willow bark, dried moss, etc.), one of the best seems to be the dried inner parts of *Fomes fomentarius*, a fungus growing on old or diseased trees. Other types of fungus, however, perform well, too (Collin et al. 1991). When a piece of fungus has begun smouldering, it is used to set fire to some easily ignited material; for example, it may be put inside a thin roll of birch bark and be gently blown on (Seeberger 1977). Friction of wood against wood can be achieved in many ways. Some well-known implements are the fire-drill (often involving a bow), the fire-saw and the fire-plough (for examples and illustrations, see among others Hough 1890, Harrison 1958; Perlès 1977).

During the Beagle expedition, Charles Darwin observed the use of a wood-on-wood technique in the Falkland Islands and in Tahiti. Concerning Tahiti, he wrote on 18 November 1835: 'The fire was produced in a few seconds; but to a person who does not understand the art, it requires, as I found, the greatest exertion; but at last, to my great pride, I succeeded in igniting the dust' (*Journal of Researches*, originally published in 1839).

Among the Australian Aborigines, men sometimes used their shield (soft wood) and spear-thrower (hard wood) together for this purpose. We know this through the work of another great explorer, W. Baldwin Spencer (1860–1929); he photographed two Aranda men using this technique in 1896 (Spencer & Gillen 1904; the photo was reproduced by Vanderwal 1987, pp. 30–31). Aboriginal women were mostly responsible for the collection of firewood. This division of labour, viz. men producing the fire and women maintaining the fire, seems to have been quite common throughout the world, though many exceptions are known. There are some indications that the production of fire was predominantly a male task in prehistory, too: fire-making equipment is mostly found in male graves (see also the section under the heading 'Strike-a-lights from the Neolithic and the Bronze Age').

The present contribution mainly concerns the technique involving percussion (or friction) of stone on stone. Different types of stone can be used. According to Perlès (1977, p. 33), it is possible to produce fire by striking flint on flint; she mentions that the Berber people in northern Africa (as well as several other peoples) use this technique. According to Oakley (1955), however, it is not possible to make fire by striking quartz against quartz; this procedure would result in cold sparks unsuitable for fire production (triboluminescence). This is also the opinion of G.J. Boekschoten (pers. comm., 1996). On the basis of experiments, Collin et al. (1991) concluded that making fire by striking two flints together is 'probably a legend' (see also Collina-Girard 1998). Flint consists predominantly of quartz. It may be noted in this respect, however, that the word 'flint' is often used in a loose sense; it may refer to material consisting not only of quartz but containing many other minerals as well; for example, most types of flint contain some iron.

It is certainly possible to produce sparks by striking two pyrites together. By far the most common technique, however, is to strike, or forcefully rub, a flint tool against a piece of pyrite (e.g., Nieszery 1992, Perlès 1977). Unfortunately, pyrite easily decomposes, particularly in sandy soils like those occurring on the North European Plain. In many cases nothing, or at most some traces of iron oxides (limonite, goethite), will remain. In most situations only the 'strike-a-light', consisting of flint, will thus survive archaeologically.

An interesting technique to make fire, to a certain extent a mixture of the two ways of making fire described above, is to strike bamboo against a sherd of china, as recorded in parts of southeast Asia (Harrison 1958, p. 219).

In historical times, the wood-on-wood technique was much more widely used than the stone-on-stone technique. Pyrite and flint were in use especially in a few peripheral areas, by Eskimos, Fuegians and Tasmanians, while the wood-on-wood technique, in many variations, was applied almost everywhere else in the world. As will be shown below, further back in time – during the Stone Age – the situation was, however, probably the reverse. This suggests that the stone-on-stone technique may have been the older of the two; at the end of the present contribution we will briefly return to this question.

Pyrite

Pyrite and related minerals such as marcasite consist of iron and sulphur (mostly FeS_2), though other elements (such as copper) may also occur. These minerals produce quite hot and relatively long-living sparks when struck or forcefully rubbed by a flint. Pyrite may occur in the form of crystals, but is found more often as more-or-less rounded or irregularly formed concretions in limestone or clay. It can also be found in secondary deposits such as moraines or beach gravels. The concretions often have diameters of 5–10 cm, but may be much smaller. In general, the characteristic golden colour of crystallised pyrite is absent on the outer surface of concretions; these have commonly a brown crust of iron oxides because of weathering.

Pyrite concretions can be collected at many places in Europe. For example, according to geologist C. Christensen (pers. comm., 1995) it occurs just about everywhere in Denmark, owing to glacial transport, but in fact is nowhere very common and really has to be searched for. Prior to the experiments at Lejre, it was attempted to collect concretions from several cliff beaches in eastern Denmark. At Møns Klint, we did not find a single pyrite in a whole day, nor did we see any traces of pyrite in the limestone layers exposed along the cliff. On the beach of Stevns Klint (well-known to geologists because of the thin 'Fishclay' layer deposited at the Cretaceous/Tertiary boundary), one nodule had been found by one of us a few years earlier. In 1995, we collected five or six fair-sized pieces during one afternoon. We also observed pyrite concretions in cavities in the lower, white limestone, dating from the Late Cretaceous (Figure 1). Such cavities, which are quite common, are often filled with different types of iron-rich concretions, including yellow, brown and red ochres. Some of these concretions consist partly of pyrite, often displaying minute gold-coloured crystals. Relatively few concretions are largely or completely pyritised. On stretches of beach where only the upper, greyish limestone, dating from the Danian, is exposed, we did not find any pyrites.

Rounded concretions of pyrite can also be found in many other limestone outcrops throughout Europe, for example on the cliff beaches of England and France. In 1996, we collected pyrite from the limestone at Cap-Blanc-Nez (Boulonnais). In the Netherlands, the 'Muschelkalk' near Winterswijk contains both concretions and crystals of pyrite (Peletier & Oosterink 1995), as well as the Lias clay exposed in the same area.

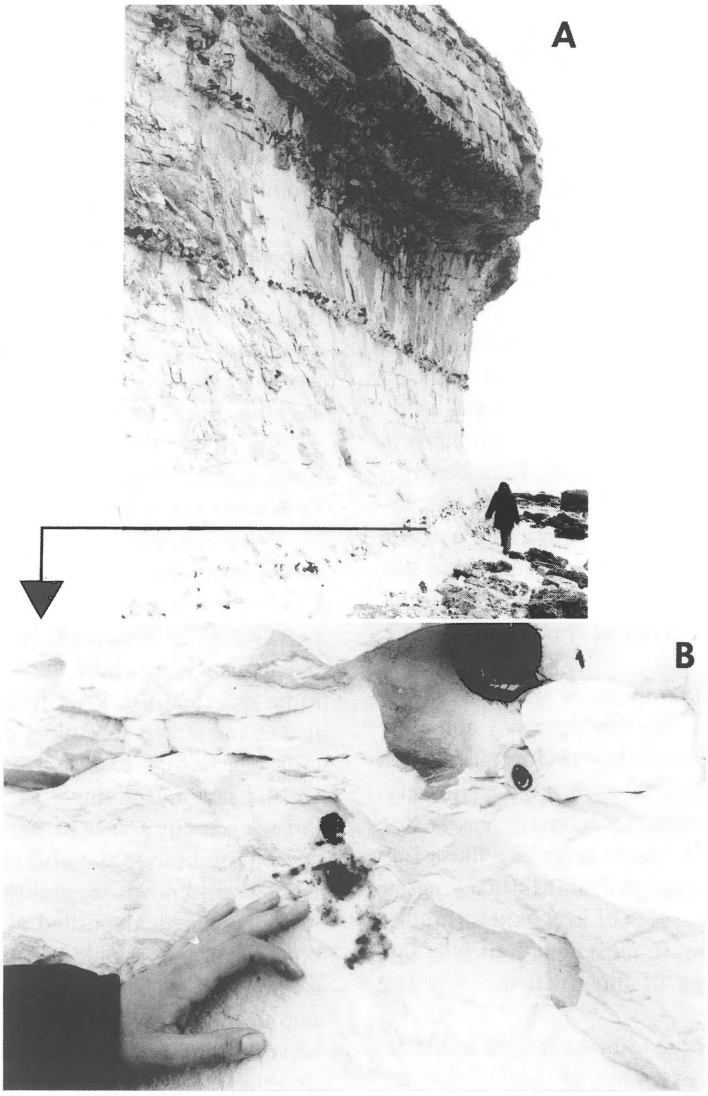

Figure 1. Stevns Klint in Denmark (photos Dick Stapert). A: general view. B: pyrite concretions in the limestone.

Strike-a-lights from the Neolithic and the Bronze Age

Many indications for the use of the flint/pyrite technique are present in the prehistoric record of Europe, but – as far as we know – none for the wood-on-wood technique. Quite a large number of graves, dating from the Neolithic or the Bronze Age, contained fire-making equipment, consisting of one or several flint tools and a lump of pyrite; in rare cases also traces of *Fomes fomentarius* have been found in prehistoric graves (see, among others, Evans 1872, Sarauw 1907, Patte 1960, Perlès 1977). Nieszery (1992) described fire-making tools from the *Bandkeramik* culture. He stated that these are found exclusively in male graves. In northern Europe, sometimes the basal parts of flint daggers were used as strike-a-lights. From male graves of the early Bronze Age in Denmark, miniature flint daggers are known (Figure 2: 1–3) that were used exclusively for this purpose, which suggests a 'ritual' role of fire (e.g. at Hvidegårdsmarken: see Petersen 1993, p. 141). 'Ice-man' Ötzi owned a strike-a-light of flint, and near him pyrite particles were also found (Egg et al. 1993, Nieszery 1992). From Switzerland (Neolithic), several rounded flints used as strike-a-lights, as well as at least one pyrite, have been found in antler hafts (Nieszery 1992, p. 361 and Figure 4). Though the preservation of organic materials is very

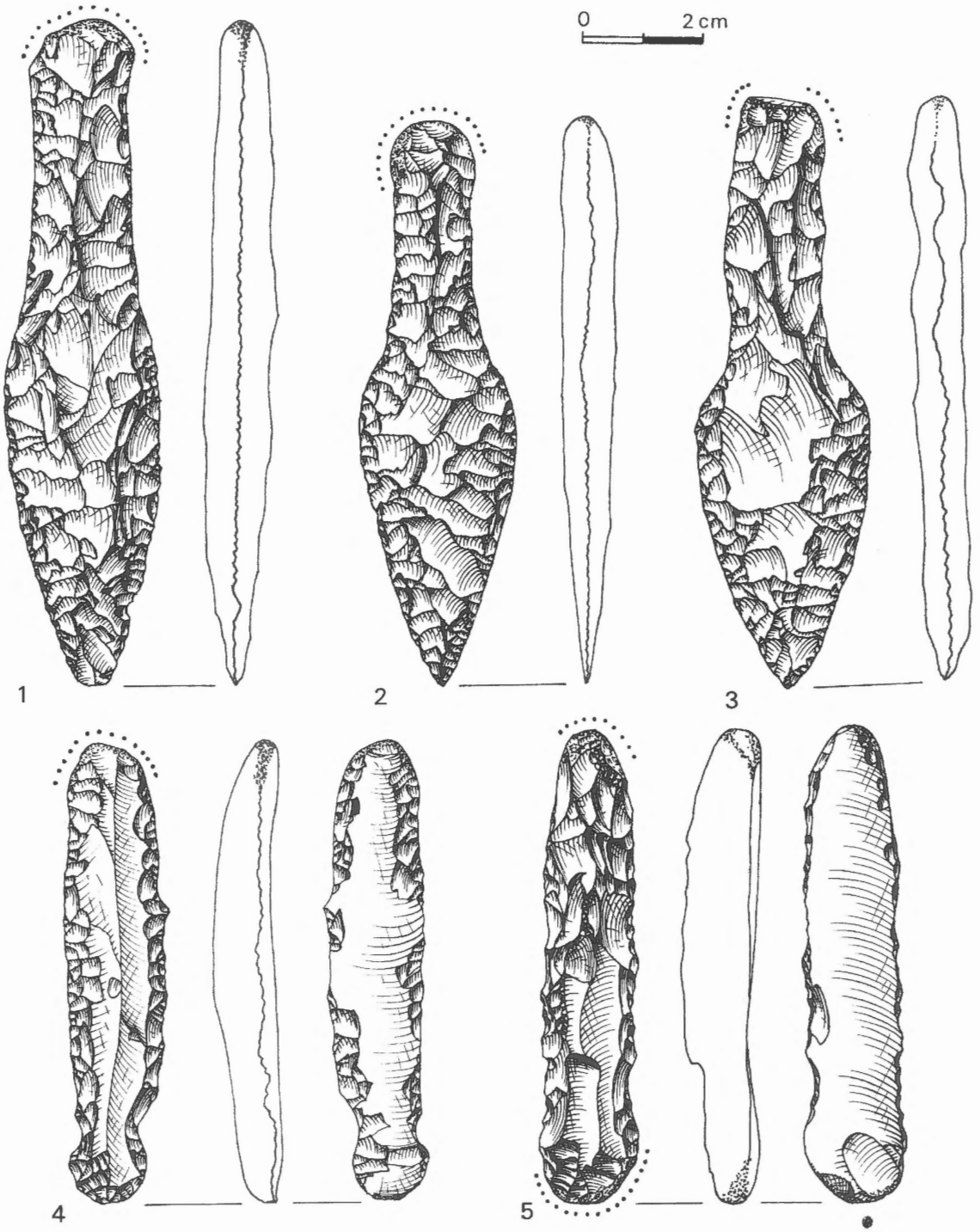

Figure 2. Flint implements (drawings Lykke Johansen). 1–3: miniature daggers used to produce fire; Bronze Age, Denmark. 4–5: bar-shaped flint implements with one or two rounded ends; Neolithic, Denmark.

good at several sites in Switzerland, distinct wooden tools for the production of fire were not identified.

Sometimes used-up cores were exploited as strike-a-lights (Nieszery 1992), but more often sturdy blades or other bar-shaped, elongated pieces of flint. Bar-shaped flint tools, with lengths of 5–10 cm and oval to round cross-sections, are common in the Neolithic and the early Bronze Age. A few examples from Denmark are illustrated in Figure 2 (4–5). Bar-shaped pieces with rounded ends are frequently found in megalithic tombs (e.g., Bakker 1979) and barrows. The grave goods from one grave in a barrow near Lunteren (the Netherlands) comprised a bell-beaker, a small copper dagger, a 'wrist-guard' of stone, seven flint arrowheads, an elongated bar-shaped flint with a rounded end (strike-a-light) and a piece of 'iron-stone' (weathered pyrite?) (Bloemers et al. 1981, p. 49).

Fire production in the Mesolithic

It is clear that the flint/pyrite technique for producing fire was in use during the Mesolithic. The most important evidence are finds of pieces of pyrite. We also possess remnants of *Fomes fomentarius* from several Mesolithic sites, for example from the well-known Early Mesolithic site at Star Carr (England), where also rounded flints and pieces of pyrite were found (Clark 1954). Pyrite and remnants of *Fomes fomentarius* were also found at the site of Duvensee in northern Germany (Schwantes 1928). *Fomes fomentarius* is furthermore known from the Kongemose site in Denmark, and from several Maglemosian sites.

Pyrites were found at several Maglemosian sites in Denmark, for example at Mullerup (this pyrite is burnt), Ulkestrup 'east' and 'east IV', Maglelyng XVIII and Sværdborg I, all on Zealand. A male grave at Nederst (Jutland), dating from the Ertebølle period, also contained a lump of pyrite (weathered), in addition to one flake axe, one antler axe, one polished greenstone axe, six flint arrowheads and two big flint knives. The pyrite was located next to the man's skull, on the floor of the grave (Esben Kannegaard Nielsen, pers. comm., 1995).

Rounded flint tools from the Late Palaeolithic: strike-a-lights?

Late Palaeolithic pyrite concretions, showing clear traces of use, are known from Laussel in France (Périgordian or Solutréan) and Chaleux in Belgium (Magdalenian) (see, among others, Perlès, 1977). At several other sites, e.g. at Vogelherd in Germany (Aurignacian) and Pincevent in France (Magdalenian), pieces of pyrite have been found which do not (or no longer) show traces of use. The nodule recovered at Chaleux has a groove probably resulting from forcefully rubbing a flint against it many times. Such grooves have also been observed on pyrites in ethnographic contexts (e.g. Nieszery 1992, Figure 2).

In northern Europe, pyrites from the Palaeolithic will in most cases not have been preserved. We have therefore concentrated on the flint tools that may have been used in the production of fire. Our experiments show that, when a flint tool has been used as a strike-a-light for some time, it will reveal a characteristic wear pattern. The wear consists especially of rounding at one or both ends of the flint, in addition to other modifications; the wear characteristics are in many cases visible to the naked eye. In the literature we found quite a few scattered descriptions of flint artefacts with rounded ends. In general, however, these have not been interpreted as strike-a-lights. Many authors have not even incorporated this tool type in their typological lists (e.g., Burdukiewicz 1986). Other authors mention the existence of this type, but without offering any interpretation. For example, Campbell (77: 13) described such pieces as follows: 'blades or flakes with one or both ends worn smooth by some rubbing process'. He noted the presence of this type in many assemblages from the Creswellian in England. Two blades with rounded ends ('lames à bout émoussé') from Gough's Cave in England (Creswellian) were illustrated, without further comments, by Leroi-Gourhan & Jacobi (1986, Figure 3: 3–4). Two blades with 'rubbed ends' from the Creswellian level in Three Holes Cave were illustrated by Barton & Roberts (1996, pp. 252–253); these are associated with a hearth dated as around 12,190 BP. In a recent publication on Hengistbury Head (England), several rounded flint tools were described, with good microscope photos (Barton 1992, pp. 120, 123), again without an explanation (though there were hints from micro-wear analysis of stone-on-stone contact: Barton 1992, p. 170; and Barton, pers. comm., 1998).

There are good reasons for this caution relating to the interpretation of rounded tools. Various processes, including postdepositional ones, could have resulted in rounding. Engraving in stone, for example in limestone or slate, is one of the possibilities. It should be mentioned in this context that flints with rounded ends

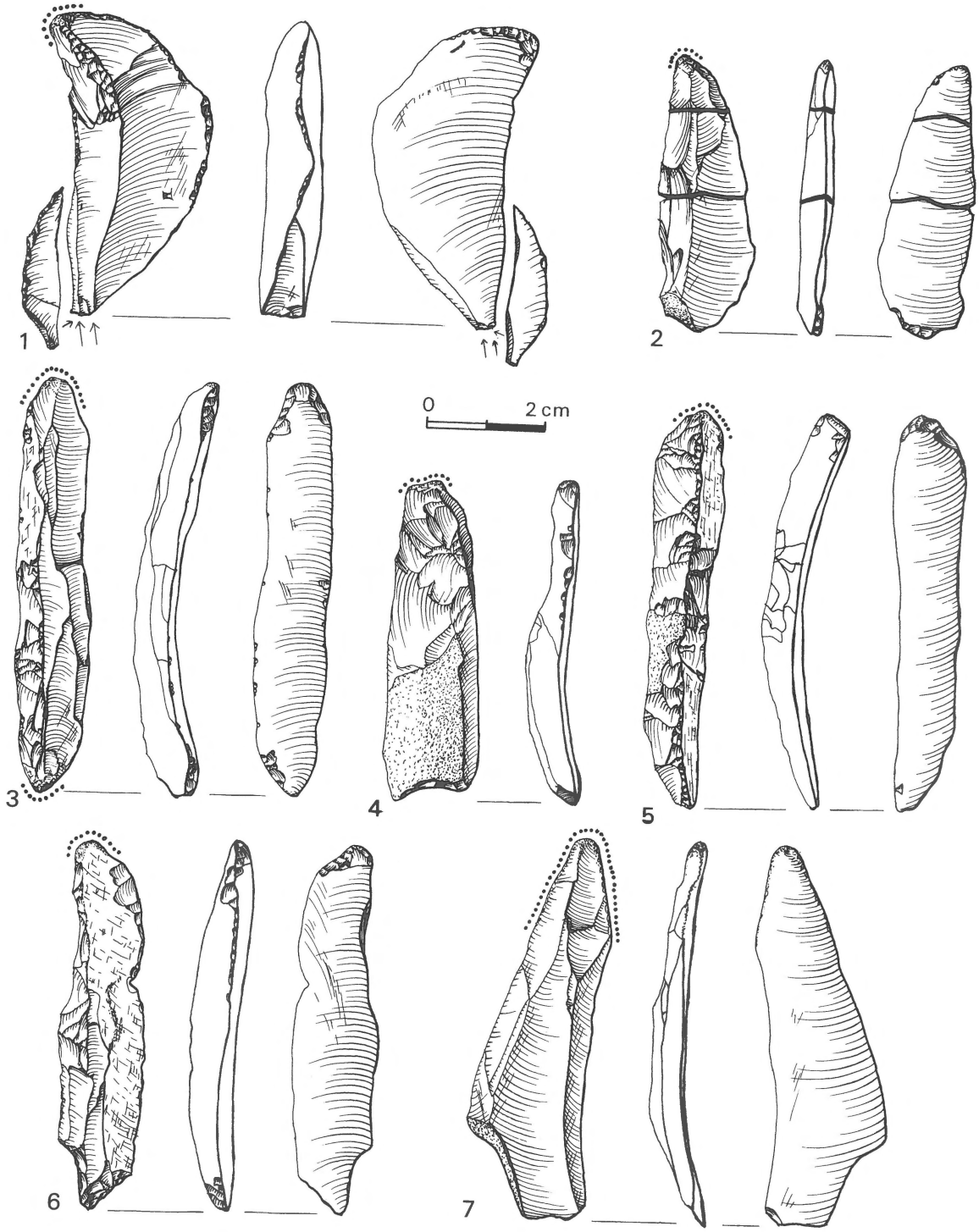

Figure 3. Flint implements with rounded ends, Late Palaeolithic (drawings Lykke Johansen). 1–2: Oldeholtwolde (Late Hamburgian). 3–6: Sassenhein (Late Hamburgian). 7: Gramsbergen I (Late Ahrensburgian).

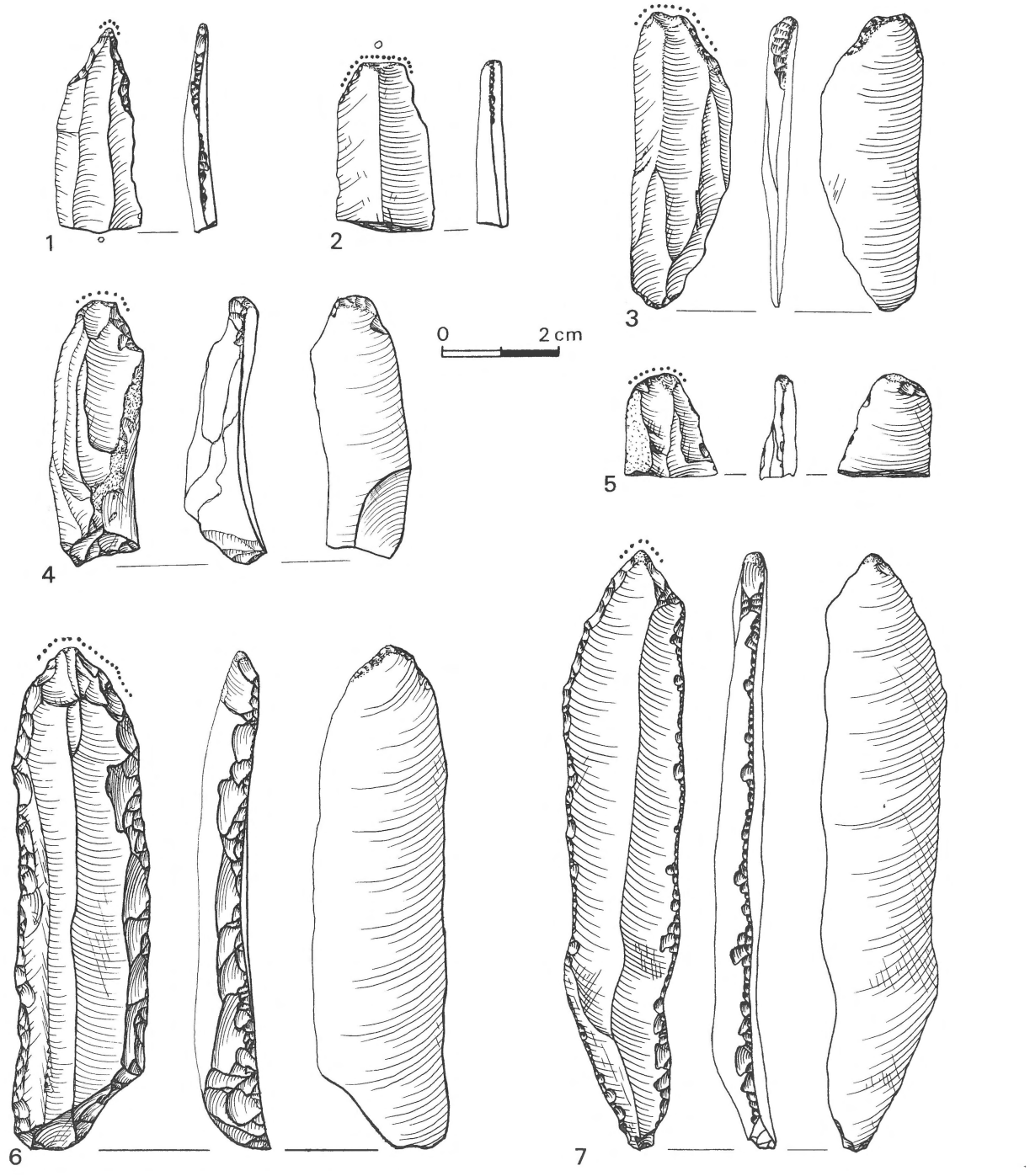

Figure 4. Flint implements with rounded ends, Late Palaeolithic (drawings Lykke Johansen). 1, 2, 4, 6, 7: Sølbjerg 3 (Late Hamburgian). 3: Sølbjerg 2 (Late Hamburgian). 5: Vledder (Late Hamburgian).

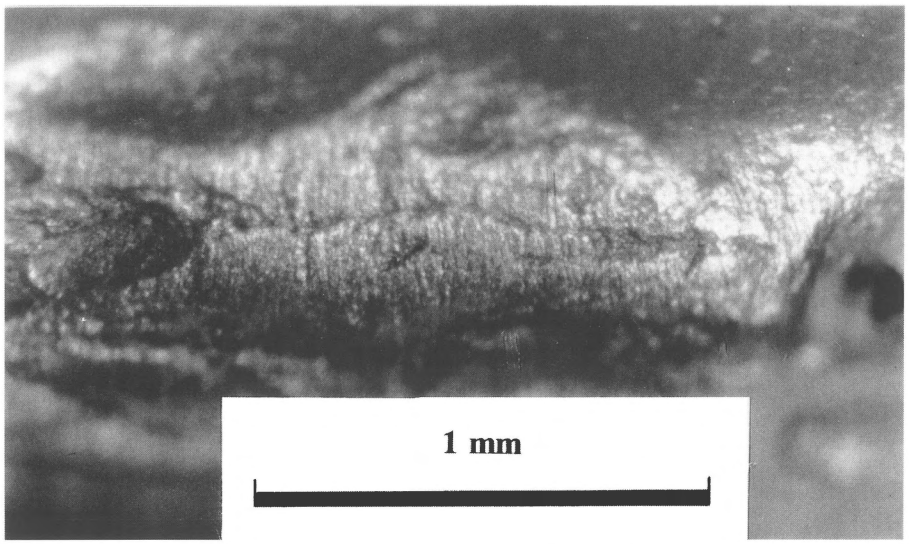

Figure 5. Stereomicroscope photo of the rounded end of a miniature flint dagger from the Bronze Age (nr. 3 in Figure 2). Photo Dick Stapert.

(especially burins, but also other tool types) are known from the Lascaux cave, which were obviously used for engraving the limestone walls of the cave (Leroi-Gourhan & Allain 1979). At other sites, too, flints with rounded ends have been interpreted as engraving tools (e.g. Lenoir & Terraza 1979).

From the Late Hamburgian site at Oldeholtwolde in the Netherlands, dating from Dryas 2 (Stapert et al. 1986), two rounded flint implements are known (Figure 3: 1–2). Both have been analysed by microwear analyst Emily Moss (Boston). One of these combines a rounded end with a burin opposite it (Figure 3: 1); one burin spall could be refitted to it. The tool was not produced at site, as it cannot be refitted in a reduction sequence with other blades or flakes and is of a type of flint unique to the site. No use wear was present at the burin edge (Moss 1988). The opposite rounded end was interpreted as being the result of use on stone; according to experiments, the rounding *could* have been the result of striking or rubbing pyrite, but the traces produced in this way were difficult to distinguish from those caused by working other types of stony material (Moss, pers. comm.). The second rounded tool from Oldeholtwolde is a blade (fragmented because of secondary frostsplitting), of which the proximal end is rounded (Figure 3: 2). Both tools show sets of striations within the rounded parts.

Among the material from the Late Hamburgian site at Sassenhein in the northern Netherlands, four rounded pieces have been identified so far (the material was only partly examined) (Figure 3: 3–6). It is notable that these are all on crested blades, which are thicker and sturdier than regular blades. One piece has two rounded ends, one of which has a borer-like shape (Figure 3: 3). Another combines a rounded end with a 'Zinken' on the opposite end (Figure 3: 6). In several cases, the rounding is associated with micro-splintering, usually on the ventral face.

Another site of the Late Hamburgian in the northern Netherlands is Vledder (Beuker & Niekus 1996), where one rounded blade fragment was found (Figure 4: 5).

On the Danish island of Lolland, southeastern Denmark, two findspots of the Late Hamburgian were excavated: Sølbjerg 2 and Sølbjerg 3 (Vang Petersen & Johansen 1994, 1996). Sølbjerg 2 produced one rounded tool (Figure 4: 3), Sølbjerg 3 yielded eight or nine specimens (Figure 4: 1, 2, 4, 6, 7). The most striking tool is a long blade, retouched on both sides; the borer-like proximal end is rounded (Figure 4: 7). Two other tools of Sølbjerg show borer-shaped rounded ends as well (the retouch is mostly ventral, and existed prior to the rounding).

Rounded tools were also identified by us among the material from several Hamburgian findspots in Germany: Meiendorf 2 (one burin), Hasewisch (one piece, with the rounded end opposite a scraper), Poggenwisch (one burin) and Teltwisch 1 (a blade and a burin).

From the *Federmesser* site of Usselo in the Netherlands (Stapert & Veenstra 1988), one rounded tool is known, a crested blade (information provided by

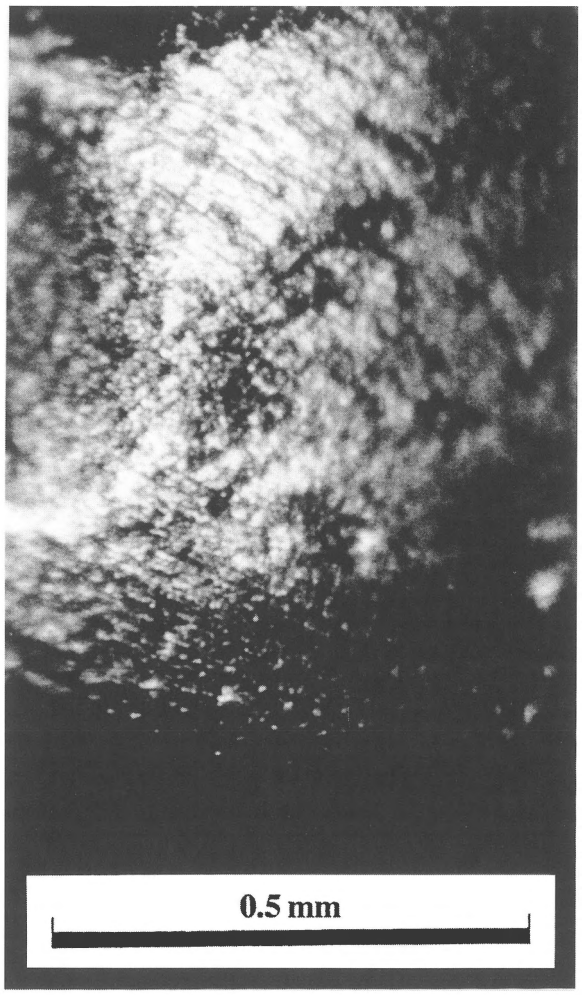

Figure 6. Stereomicroscope photo of the rounded end of the blade fragment from Vledder (Late Hamburgian). Photo Dick Stapert.

A.L. Zandbergen). Another rounded tool of the *Federmesser* tradition, from a site at Westelbeers in the southern Netherlands, was decribed by Arts & Deeben (1976, 26 and their fig. 20: 65).

Finally, the Late Ahrensburgian site of Gramsbergen in the Netherlands (Johansen & Stapert, in press) produced one specimen; the proximal part of a blade is very strongly rounded, over a considerable length (Figure 3: 7).

A few microscope photos of some of these rounded flint implements are shown in Figures 5–9. Especially notable are the dense sets of parallel striations within the rounded ends.

At the above-mentioned sites of the Hamburgian in the Netherlands and Denmark, no engravings in stone, nor perforated stone pendants were found. It seems reasonable to assume that the tools with rounded ends were used as strike-a-lights. It would be nice, however, to posses some independent evidence to corroborate our hypothesis.

One possibility would be to look for residues: fine particles of pyrite embedded in depressions on the surface of the rounded parts. The burin of Oldeholtwolde was analysed in the eighties by Dr G. Boom (then attached to the Department of Applied Physics of Groningen University). He used a scanning electron microscope (SEM), coupled to a spectrometer for chemical analysis on element level. Boom discovered two minute particles containing sulphur and iron; one also contained copper. These *could* be pyrite or marcasite particles. We cannot be totally certain, however, because a mineralogical determination was not attempted. In the nineties, Mr H. Bron of the same department looked at a series of rounded tools, including several specimens excavated from Hamburgian sites in the Netherlands and Denmark. He found a few particles containing sulphur and iron (these particles seem also to contain several other elements, however). The best example is a rounded tool from Sølbjerg 3 (Johansen, in press). These preliminary results are encouraging, and we hope to continue this line of research.

It is likely that closer examination of Late Palaeolithic lithic assemblages in Europe will produce many more examples of tools with rounded ends. Reports on use-wear analyses of Late Palaeolithic flint material in most cases do not contain descriptions of such tools. We suspect that the reason for this lack is the fact that high magnifications were used for these analyses, in order to identify tiny areas of polish along 'working edges'. The rounding we are concerned with in the present contribution is much coarser than the types of wear observed in high-magnification analyses, and therefore may have escaped attention. Another reason might be that these implements are quite rare, and therefore had little chance to end up in the analysed samples.

The experiments at the Lejre Experimental Centre

In 1995, we carried out experiments at the Archaeological-Historical Experimental Centre at Lejre in Denmark, together with a group of Scandinavian students of archaeology. Flint tools similar to the prehistoric ones described above were used on a range of materials, including hard and soft limestone,

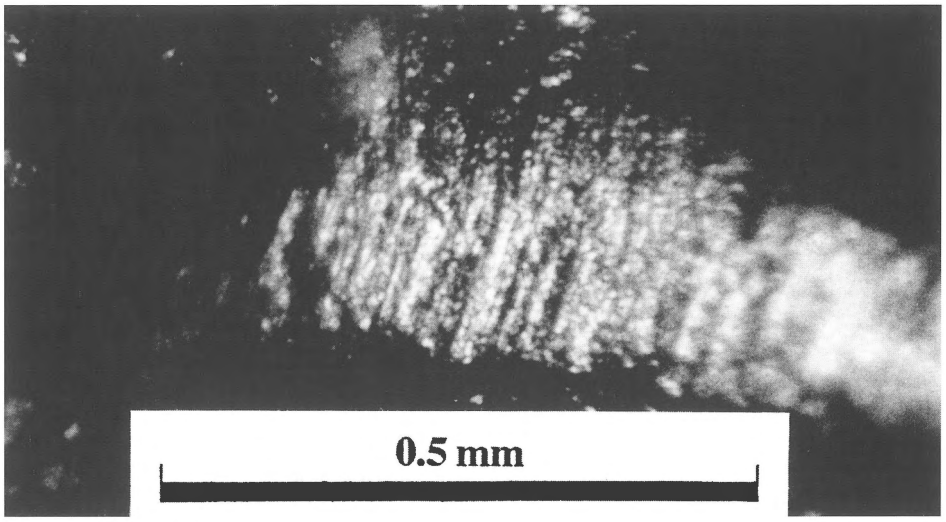

Figure 7. Stereomicroscope photo of the rounded end of the blade fragment from Vledder (Late Hamburgian). Photo Dick Stapert.

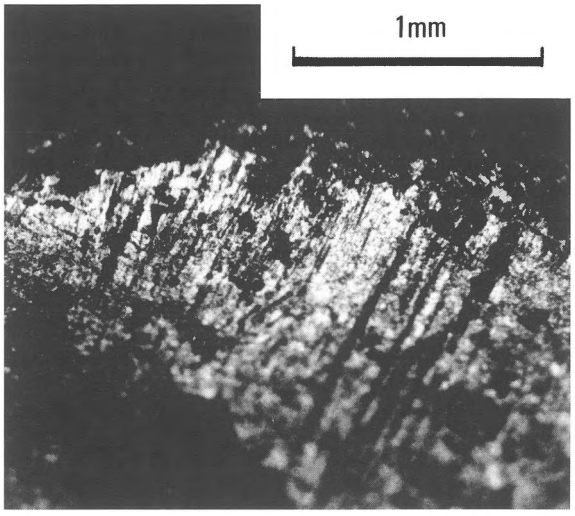

Figure 8. Stereomicroscope photo of the rounded end of a flint implement from Sølbjerg 2 (Late Hamburgian). Photo Dick Stapert.

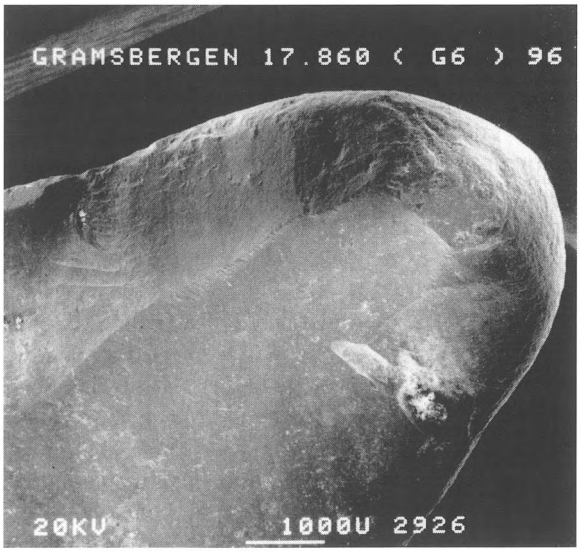

Figure 9. SEM photo of the rounded end of a blade from Gramsbergen I (Late Ahrensburgian). Photo H.J. Bron.

slate, quartzite, sandstone, hide (cow) and pyrite. After use, these tools were examined under a stereomicroscope. The main goal was to see if use on pyrite would produce characteristic wear patterns, distinct from other types of wear. If this proved to be the case, it would supply archaeologists with a relatively easy method for identifying strike-a-lights of flint. Some of the experimental pieces were also inspected by Mr Bron, using the SEM. The results will be described in more detail elsewhere; a brief preliminary account must suffice here.

On the basis of ethnographical sources, and guided by the directions of striations occurring on the rounded tools from the Hamburgian described above, we knew that we had to strike or rub the pyrite (held in one hand) with the flint tool, held in the other hand. After some practice we were able to produce sparks quite easily in this way. We observed that the best method of making sparks was to press the flint to the pyrite with some force while forcefully rubbing the pyrite rather than striking it, moving downwards (assuming that the tinder is placed below: see Figure 10). Normally, each rub would produce sparks.

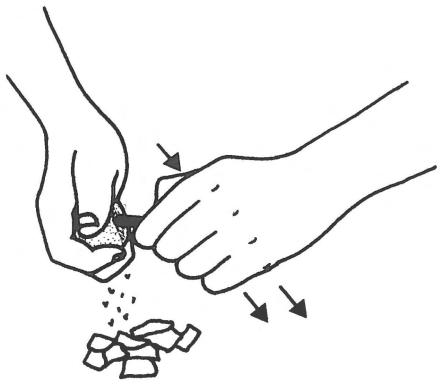

Figure 10. Schematic drawing illustrating the production of sparks by forcefully rubbing a pyrite with a flint implement. Drawing Lykke Johansen.

After a few hours of rubbing, a groove developed in the pyrite. As soon as there was a groove, it was easier to produce sparks. Most probably, this is because the outer surfaces of the pyrite nodules are weathered; the fresh, unweathered mineral in the core of the concretions works better. Moreover, when a groove is present, a larger contact area between the flint and the pyrite is achieved. The groove we were gradually producing was very similar to the one on the pyrite nodule from the Magdalenian site at Chaleux in Belgium.

It has been suggested that at least some rounded tools from the Late Palaeolithic were used for engraving in limestone, especially at cave sites. Therefore, we also used experimental tools to engrave both soft and hard limestone. Hard limestone came in the form of polished slabs of a dense type of travertine. Slabs of soft limestone were collected at Stevns Klint. It was hardly possible to engrave the travertine with flint tools. Even with great effort, only a few straight lines could be produced in half an hour of work. Producing curved lines by engraving was out of the question. The soft limestone, however, was very easy to engrave, without applying much force, and it was possible to make lines of all shapes. Slate, too, is a material that is easy to engrave; the experimenters held the flint tools in the hand like a pencil, and needed only moderate force. We tried to engrave a pebble of fine-grained sandstone. The experimenter scratched the tool to and fro for twenty minutes in the hope of making some lines, but the sandstone was simply too hard to allow any engraving; only superficial scratches were produced. We also worked a piece of quartzite for twenty minutes, again scratching the stone to and fro. Hardly any result was visible on the stone. Most quartzites are too hard for engraving with flint.

One experimental tool was used for boring thick cow-hide. After forty minutes, only six holes were produced. Relatively massive 'borers', such as our experimental tools, do not seem to be efficient tools for piercing or boring hide (bone awls would perform much better). Another tool was used to bore into slate. The experimenter drilled six holes, to a depth of 0.5–0.9 cm, within twenty minutes. He rotated the borer in both directions. It was easy to bore holes in slate with the experimental tool. One tool was used for boring into sandstone for thirty minutes. It was only possible to create one small depression in the surface of the stone (to a depth of approx. 2 mm) in this timespan. Sandstone is too hard for this. Another tool was used to bore holes in the soft limestone from Stevns Klint. In twenty minutes, eight holes were produced to a depth of about 1 cm; the work was relatively easy.

A range of attributes can be observed with a stereomicroscope. They were listed, so that the observations could be systematically recorded for each tool; the checklist included the following phenomena: crushing/splintering, cracks in the surface, 'micro-potlids', rounding, scratches, gloss and residues. It should be noted that several of these attributes can occur in combination within one area on a tool.

One stereomicroscope photo of an experimental flint tool used on pyrite is shown in Figure 11. Repeated use of flint on pyrite typically resulted in distinct rounding of the flints, very similar to the rounding observed on Late Palaeolithic specimens. In itself, this is already a satisfying result of the experimental work. The rounding is combined with other types of modification. It is the characteristic combination of particular attributes that makes it possible to identify use on pyrite, and to distinguish this from other types of use. Within the rounded parts, massive striations can be observed: sets of subparallel scratches, densely packed together. Numerous striations on flint tools resulting from use on pyrite were also mentioned by Collin et al. (1991). In addition to massive scratching, the rounded areas show a fairly high gloss. Several other attributes may also occur, such as crushing or splintering. An interesting feature, which is not limited to flints used on pyrite, is the development of 'micro-potlids': little roundish parts of the surface that splintered away as a result of friction heat. These seem to be associated with the forceful engraving of hard materials. We observed this phenomenon both on several experimental tools, and on one archaeological specimen. These

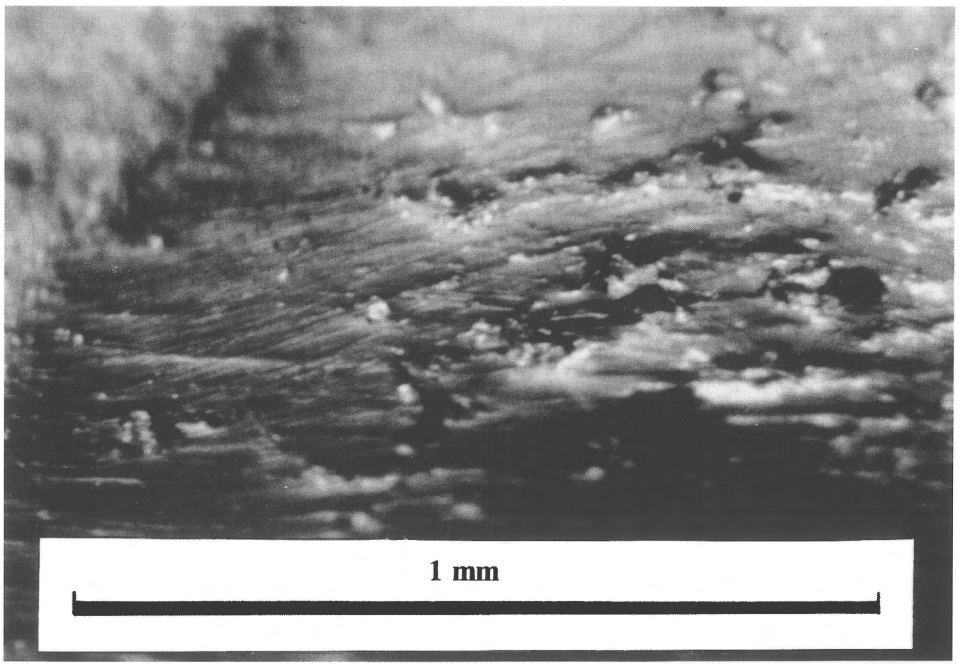

Figure 11. Stereomicroscope photo of an experimental flint tool, used on pyrite for ten minutes (after washing the tool). Photo Dick Stapert.

micro-potlids are typically associated with cracks in an approximately 'hexagonal' pattern.

Microscope photos were also made of the tools used on other materials than pyrite, but are not described in detail here (a series of microscope photos were included in Johansen & Stapert 1996). All experimental tools used on materials other than pyrite show very different patterns of use wear; particularly notable is the absence of dense sets of striations. It appears that the combination of distinct rounding, gloss and massive scratching is quite characteristic of flints repeatedly and forcefully rubbed onto pyrite in order to produce sparks. Although this result is encouraging, it does not prove conclusively that the rounded flint tools presented above were strike-a-lights. For definite conclusions, many more experiments would be necessary, and also more extensive analyses. Yet, the use wear on the archaeological specimens is very similar to that on the experimental pieces employed on pyrite, indicating at least that they *might* well have been used for this purpose. The similarity not only concerns the specific combination of types of wear, but also the scale of the modifications in terms of surface area, coarseness and density.

Rounded tools from Palaeo-Eskimo sites in Greenland

An unexpected result of the work described above was the identification of similar rounded tools among the material from several Palaeo-Eskimo sites in western Greenland. During the past two decades, several dozens of Palaeo-Eskimo sites were excavated in the Disko Bay area along the west coast. The sites are ascribed to the Saqqaq culture (approx. 2500–1000 BC) and the Dorset culture (approx. 800 BC–AD 1000). The historically known Eskimos are representatives of the Thule culture, from about AD 1000 onwards (chronology after Grønnow, 1988).

We are involved in a project aiming at the spatial analysis of one of the richest Palaeo-Eskimo sites in this region, known as 'IT' (short for 'Ikkarlusuup Tima'); it is situated on an island in Disko Bay. The site was excavated in 1993, 1995 and 1996; the second author took part in this work. 'IT' is ascribed to the Dorset culture and probably dates from the first millennium BC. At least three dwelling structures were found, the largest of which was analysed by the ring and sector method (see Stapert & Johansen 1995/96). Quite to our surprise, we encountered several tools with rounded ends in the material of 'IT', which reminded us of the rounded Palaeolithic flints from Europe described above (Johansen & Stapert 1997).

Figure 12. Producing fire with the fire drill (wood-on-wood technique). Angmagssalik, eastern Greenland. After a photo in Birket-Smith 1927 (p. 121). Drawing Lykke Johansen.

Our observation was surprising because the historical Thule Eskimos in Greenland are known to have produced fire mainly with the wood-on-wood technique; only in the extreme northwest (the Thule area north of Melville Bay) did people employ the technique involving pyrite (Birket-Smith 1929). This is in contrast to the Thule Eskimos in Canada and Alaska, who used both the fire drill (wood-on-wood) and the flint/pyrite technique. An important source concerning traditional ways of life in Greenland is the work by Gustav Holm (1849–1940), a naval officer who was one of the first to visit the Angmagssalik area along the east coast of Greenland, in 1883–1885 (the Umiak expedition). Holm collected many artefacts from the area, and described the culture of the native Eskimos. His collection includes a series of fire drills, but no pyrites nor strike-a-lights made of stone (Wulff et al. 1985). Holm observed the use of the fire drill, operated by two people (see Meldgaard 1985). Much later, the same technique was described and photographed by Birket-Smith (1927); Figure 12 was drawn after a photograph in his book.

At quite a few Palaeo-Eskimo sites in Greenland, preservation of organic materials is excellent. Not only bones but also wooden objects have often survived. Qeqertasussuk ('QT') is a site of the Saqqaq culture in Disko Bay, where many wooden artefacts such as knife-hafts, bowls, spoons and paddles were preserved (Grønnow 1988). Characteristic wooden tools for the production of fire are, however, absent (Grønnow, pers. comm., 1997).

So far, we identified stone implements with rounded ends in the material from at least four Palaeo-Eskimo sites in western Greenland. The sites stem from both the Saqqaq and Dorset cultures. Nine such tools were found at the 'IT' site (Figure 13). These were in most cases re-used and often broken 'burin-like tools'; the primary function of these polished implements is unknown. Most of the rounded artefacts were located close to hearths (Stapert & Johansen 1995, 1996, p. 68). We are convinced that these were strike-a-lights, used in combination with pyrites. Pyrites were found at several Palaeo-Eskimo sites in this region, for example at Qeqertasussuk ('QT'), where also at least one rounded tool was present.

The rounded implements in Greenland are not made of flint but of silicified slate ('killiaq'). We used experimental tools made of this material on pyrite, and studied the resulting use wear. Both the experimental pieces and the rounded objects from the archaeological sites show the same combination of use-wear traces as described above for the European flint artefacts: dense sets of subparallel striations in addition to gloss and rounding (see, for two examples, Figure 14).

In view of these results, the stone-on-stone technique seems to have been the oldest in Greenland. In fact, no real evidence for the wood-on-wood technique exists for periods predating the Thule culture.

Discussion

There has been quite a lot of speculation concerning the question of how the production of fire was discovered, and which technique was applied first. Some authors believe that the observation of sparks produced during flint-knapping inspired the discovery. John Evans (1872, p. 281) suggested that the use of pyrite nodules as hammerstones for flint-knapping might have triggered the invention of fire-production. Producing flint artefacts by percussion is an ancient art, some 2–2.5 million years old. According to Hough (1890, p. 571), the flint/pyrite technique was the 'original discovery', gradually replaced by wood friction because this technique is easier to apply, and the necessary materials easier to obtain; this opinion is shared by Sarauw (1907) and other authors.

Our work seems to support the idea that the flint/pyrite technique was indeed the oldest. As noted above, we have no unambigous indications for the wood-on-wood technique for the European Stone Ages (Late Palaeolithic, Mesolithic, Neolithic) and the Bronze Age; we possess only evidence for the use of flint and pyrite. Most of the historically known Eski-

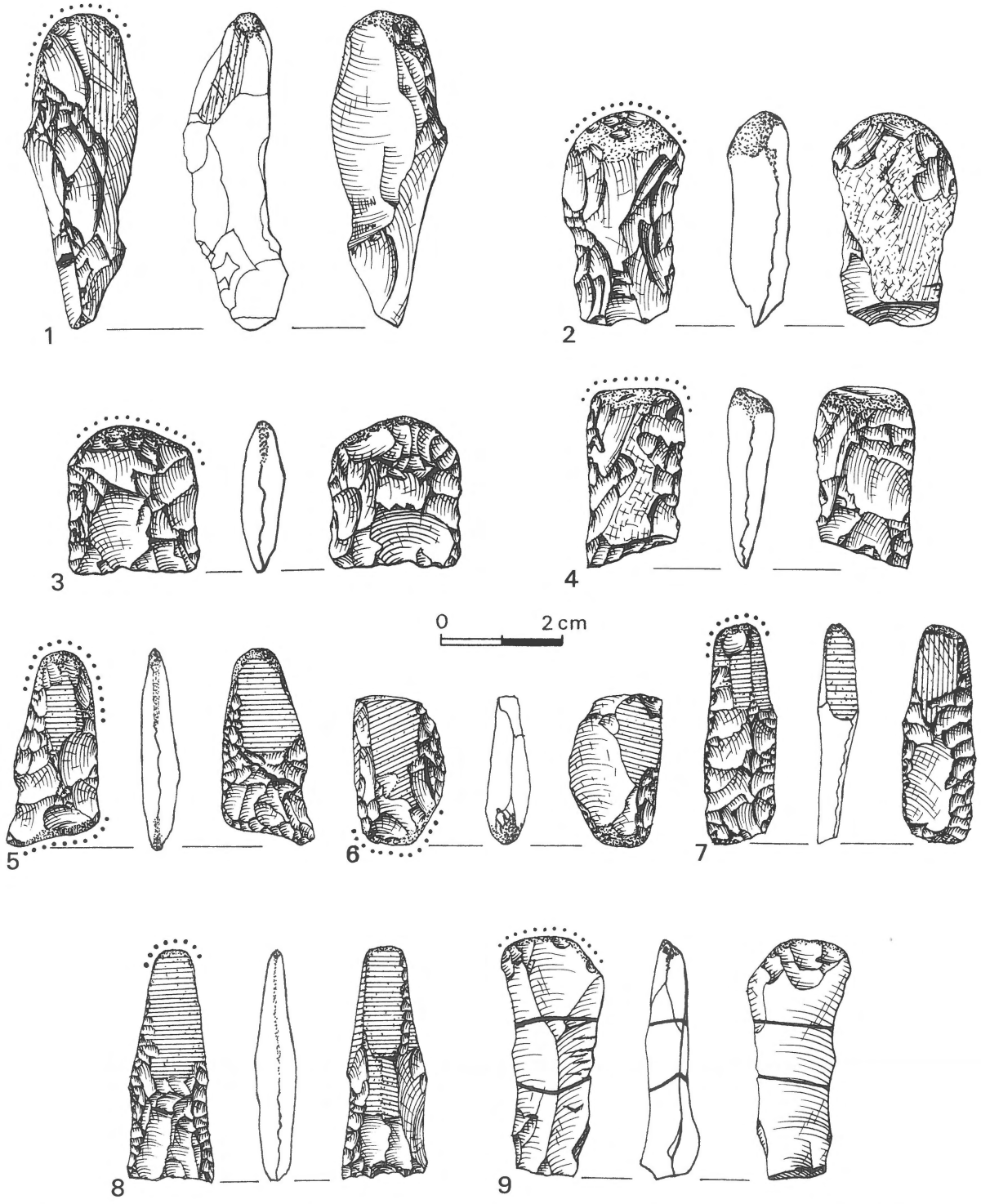

Figure 13. Nine tools with rounded ends from the 'IT' site, western Greenland (Dorset Culture). These implements are made of silicified slate. Drawings Lykke Johansen.

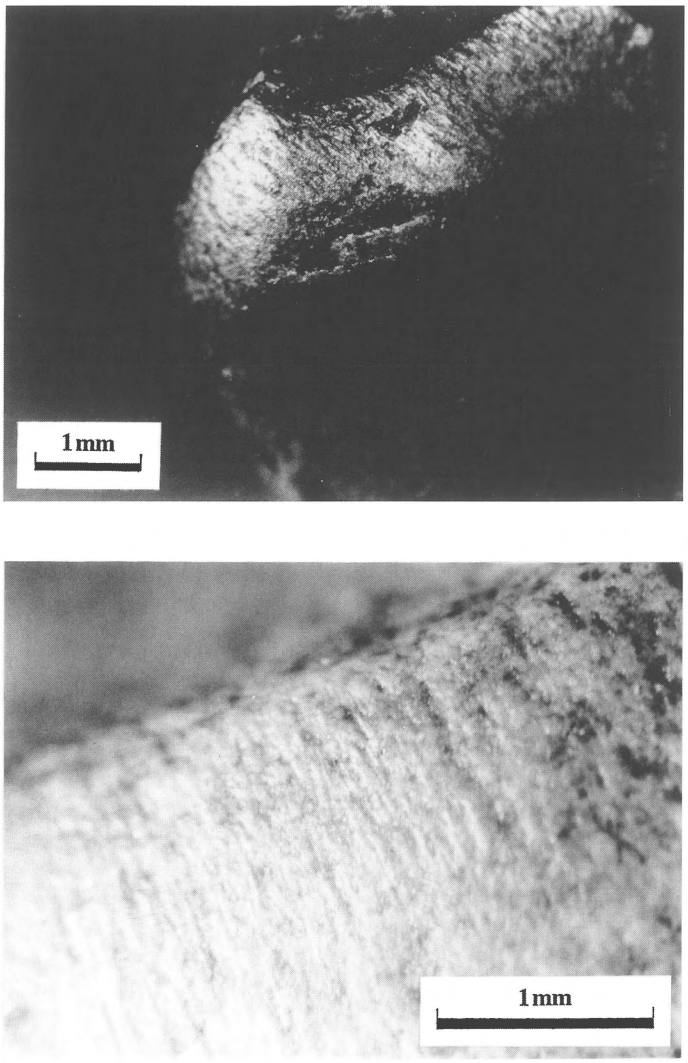

Figure 14. Stereomicroscope photos of two rounded implements from the 'IT' site, western Greenland (top: nr. 7 in Figure 13, bottom: nr. 4 in Figure 13). Photos Dick Stapert.

mos in Greenland (Thule culture) used the wood-on-wood technique, though the flint/pyrite technique was known to them (and also used, at least in northwestern Greenland and Canada). The bearers of the preceding Saqqaq and Dorset cultures, however, probably produced fire only with flint and pyrite.

To us, an important question is how Middle Palaeolithic people produced fire. Distinct hearths are known from this period, for example at Pech de l'Azé (Bordes 1972). Some wooden objects from the Middle Palaeolithic have been interpreted as fire-making tools, such as a 8.5 cm long specimen from Krapina (e.g., Perlès 1977). These examples do not seem very convinving, however. So far, distinct rounded flint tools dating from the Middle Palaeolithic have hardly been mentioned in the literature. Middle Palaeolithic tools often suffered much more severely than Late Palaeolithic artefacts from natural weathering processes, such as rounding in gravelly river beds, patination, etc., and are therefore in most cases not suited for use-wear analysis. It is known, however, that rounded flint implements do occur in the Middle Palaeolithic, for example at Buhlen in Germany (L. Fiedler, pers. comm., 1998), but these have not yet been analysed by use-wear specialists. Pyrite has been found at the Mousterian site of Grotte de la Hyène in France (by A. Leroi-Gourhan; after Feustel 1973). Remnants of *Fomes fomentarius* have been found at the Middle Palaeolithic site of

Salzgitter-Lebenstedt in Germany (Tode 1953). These few indications are not enough for concluding that fire was produced using flint and pyrite during the Middle Palaeolithic, and it would be important to investigate this matter further, on the basis of well-preserved flint assemblages.

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