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Abstract

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Through ethnographic accounts and modern experiments it has been observed that careful heating of silica materials improves their flaking qualities. Using the scanning electron microscope, tests were carried out on a Mesolithic microblade, two Neolithic daggers, a Neolithic sickle and a Neolithic thick-butted axe, to determine if these objects had been heat treated prehistorically. Results indicated that this technique was not used and was probably unknown during the Stone Age in southern Sweden.

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1. Introduction and Background

The handicraft skill manifested in the flint artifacts from the Mesolithic and Neolithic periods contains a large amount of information which has resulted in a considerable number of different artifact types. Most of this information includes knowledge about where, how and with what force percussion has been directed at the flint in order to achieve the effect intended. This aspect of flintknapping has been thoroughly studied during recent years.[1] Another aspect of the handicraft skill involves a detailed knowledge of which raw material was most suitable for different types of artifacts. Not even the most skilled knapper was able to produce a good product if he did not have access to good raw material. Therefore, much effort was spent in obtaining and choosing the most suitable type of flint for the tools to be manufactured. There are several examples of finds containing tools knapped from a raw material not to be found in the immediate proximity of the find-spot. The Mesolithic sites around the bog Ageröds mosse contain examples of this phenomenon. Both the finished tools and the waste consist almost entirely of flint transported to central Scania from the west coast.[2] The number of pieces made of local flint is less than one per mille of the total flint finds. The distance from the sites to the closest location of the moraine flint is no more than 13 km as the crow flies, but the total amount of flint proved to be several tons.

Indication of long-distance flint transport is found on Norrland sites, where the finds increase about 2000 b.c.[3] Most well-known are the hoards of finished axes found in Norrland. These were probably transported from southern Scandinavia in their present state.[4] As such the hoards are not evidence of northern flintknapping, but such evidence can be found on the sites where the number of flakes increases simultaneously with the import of finished products.[5] In southern and central Sweden there are several examples of flints found on Mesolithic and Neolithic sites where the nearest flint source was hundreds of kilometers away.[6]

Local flint is available in central and northeastern Scania, but it is of such poor quality that it has rarely been used when making products requiring an advanced knapping technique. This is the so-called Kristianstad flint, whose fossil and chalk inclusions make it difficult to knap. The result is that this kind of flint was not used at all if the distance to better quality flint was not too great. If it was used, it was only used in the manufacture of

[1] Crabtree 1968; Bordes & Crabtree 1969; Hester & Heizer 1973; Callahan 1979; *cf.* the periodicals Flintknappers' Exchange and Lithic Technology with several articles on this subject.
[2] Larsson 1978, p. 190 f.

[3] Baudou 1977, p. 30.
[4] Becker 1952, p. 33 ff.; Malmer 1962, p. 506 ff.
[5] Baudou 1977, p. 139 f.
[6] Sundelin 1920, p. 143 ff.; Welinder 1977, p. 3.

simple tools. The lack of larger artifacts of Kristianstad flint is probably due to the difficulty of finding sufficiently large nodules. It is striking how very few Neolithic axes are made of this kind of flint.[7]

But the knowledge of the qualities of flint most probably included more than a pure understanding of the different kinds of raw material. An awareness of material defects such as fossil inclusions or frost cracks at an early stage of knapping could considerably reduce required work time. It is possible that settlement debitage consisting of flint flakes which are distributed in a very limited area and which can be conjoined into larger pieces comes from flint cores which were aborted in the early stages of knapping.[8]

There have also existed certain ways of altering the flaking qualities of flint. Anders Kragh, the late Danish flintknapper, who with great success copied several Stone Age artifact types, preferred to work with flint which he had soaked in water for several weeks.[9] He was able to show by practical tests that a considerable volume of water can be absorbed by the flint.[10] However the advantage of soaked flint for an experienced flintknapper has been questioned.[11]

That color changes result when flint is heat treated has long been known. In archaeological research, the information about color changes has been used to locate hearths lacking boundaries.[12] Other changes in flint when heat treated were also well-known during prehistoric times. Excavations of megalithic tombs in southern Scandinavia and northern Germany have revealed amounts of heated flint in different areas of the construction.[13] Very often the heated flints are concentrated to the floor level. As a consequnce of such observations being made in some megalithic tombs in southeastern Scania, experiments were carried out to study how flints change after being heated.[14] In these experiments the flints, both the Kristianstad and the Danian varieties, were exposed to heating for 10 to 25 minutes, after which they were cooled in air and cold water, respectively. No typical bulbar waste flakes were produced when Kristianstad cores heated for 25 minutes were knapped. However, a flint core heated for 10 minutes produced typical bulbar flakes when it was knapped. Traces of heating occurred only sporadically. Cooling by means of cold water did not facilitate the knapping of the core. No visible effects of the treatment could be seen on a core of Danian flint which was heated for 20 minutes. However when this core was knapped there were no clear characteristic bulbs of force or waves on the flakes, while such phenomena were visible on flakes from cores heated for 10 minutes. The conclusion of these experiments was that heating flints resulted in a considerable reduction of work when the purpose was to produce small pieces of flint to be mixed in clay as a simple temper. However, it was doubted that this method was used in manufacturing flint tools.[15]

Ethnographic accounts from the latter part of the 19th century describe how heat treatment was used to facilitate the knapping of flints or of materials whose qualities closely resemble those of flint, i.e. silica materials. These accounts originate from Bengal,[16] the western part of Oceania,[17] northern Australia,[18] southern Africa[19] and several areas in North America.[20]

According to the descriptions, the heat treatment was carried out in many different ways. In Bengal the cores were covered with wood which was then burned. After a time water was poured on the fire so as to achieve a sudden drop in temperature, resulting in a splitting up of the cores.[21] The Yurok Indians of California used a similar technique. They put the cores in the fire, cooled them rapidly and then knapped them.[22] In present-day Zimbabwe there is information from the An-

[7] Cederschiöld 1949, p. 53; 1950, p. 363 f.
[8] Larsson 1981, p. 4 f.
[9] Kragh 1964, p. 12.
[10] Kragh 1964, p. 19 ff.; Patterson & Sollberger 1979, p. 50; Andersen 1981, p. 2.
[11] Pond 1930, p. 21 ff.; Callahan 1979, p. 64.
[12] Larsson 1978, p. 194 f.
[13] Strömberg 1971, p. 228 ff.; Schuldt 1972, p. 47 ff.
[14] Strömberg 1971, p. 222 ff.
[15] Strömberg 1971, p. 227; *cf.* Strömberg's article in the present volume.
[16] Man 1883, p. 380.
[17] Powell 1884, p. 160 ff.
[18] Elkin 1948, p. 110.
[19] Robinson 1938, p. 224.
[20] Schumacher 1874, p. 355 f.; Powell 1875, p. 27 f.; Miller 1897, p. 207; Frazer 1908, p. 68; Eames 1915, p. 67; Nagle 1914, p. 140; Lehmann 1927, p. 92 ff.; Voegelin 1938, p. 28; Goldschmidt 1951, p. 419.
[21] Elkin 1948, p. 11.
[22] Schumacher 1874, p. 355.

goni tribe about direct heating of the raw material, after which it was placed on an anvil and knapped.[23] The method which involves heating the material and then cooling it in water is mentioned by several persons, claiming to be eyewitnesses, in Canada, USA and Mexico.[24] Several archaeologists have doubted this technique of direct exposure to fire, and because of this have questioned if the earlier accounts were merely a misinterpretation since the observers were not themselves familiar with flintknapping.[25]

Experiments with this technique have not yielded positive results. Experiments performed by some archaeologists have indicated that this heat and drip method is not a likely method of tool manufacture. It is not possible to control flaking with this method. In addition, the pieces produced are filled with cracks, making further knapping impossible. It has also been shown that heated materials do not always crack when water is dripped on their surface.[26] In central Australia this technique of fire exposure was used in recent times not when knapping flint, but to break loose a chunk of silica material small enough to carry.[27]

Besides the course of action mentioned above, there are accounts of other ways of heating which have been practiced. Among the Shoshoni Indians the raw material was roughly knapped and then buried in earth above which a fire was built. After the fire had burned down, the material was not touched for several days in order to prevent too rapid cooling.[28] According to another ethnographer the heating period was extended for five days.[29] The Shoshoni Indians and the Shivwits Indians could also bury flints together with charcoal.[30]

These accounts of heat treatment did not get the same attention in the literature as the more drastic one with rapid temperature change, and for a long time interest concentrated only on the latter method.[31] Not until the method of using more careful heating and cooling was tested by Don Crabtree did the study of and experiments with heat treatment become an important part of understanding the knapping of silica materials.[32] Crabtree experimented with heat treatment for many decades, but because of the distrust of this method it took several years before his work was accepted by professional archaeologists.[33] Crabtree discovered that different silica materials demand different kinds of heat treatment. He was able to determine a minimum temperature limit, below which no change occurred in the material, as well as a maximum temperature at which cracking begins. The major change that Crabtree could register after materials had been heat treated was that they were easier to shape by pressure-flaking. It was possible to detach larger flakes from a heated core than from an unheated core.[34] Crabtree's article with the description of heat treatment ended with a number of questions concerning the use of heat treatment chronologically as well as geographically.[35] These questions initiated several studies of heat treatment seeking archaeological and ethnographic evidence around the world. Different means of identifying heat treatment were also drawn up.

When in the 1930s Crabtree started his experiments with heat treatment, he used a sand bath in which the pieces were buried before they were heated.[36] He later used a pottery kiln in order to control the temperature better. He suggested that heat treatment was carried out prehistorically by burying the silica material in the earth below the hearth. This method of heat treatment has also been observed among certain Indian tribes in the US, as mentioned above. This method has been tested experimentally, and it seems that a high temperature and a long heating period are required before any changes whatsoever occur.[37] We experimented with heat treatment of Scanian Seno-

[23] Robinson 1938, p. 224.
[24] Frazer 1908, p. 68; Nagle 1914, p. 140; Lehmann 1927, p. 93 f.
[25] Holmes 1919, p. 364; Pond 1930, p. 25; Squier 1953, p. 25 f.; Ellis 1965, p. 43; Purdy & Brooks 1971, p. 322 ff.; Sollberger & Hester 1972, p. 183.
[26] Mandeville 1973, p. 179.
[27] Personal information from Professor Lewis Binford.
[28] Powell 1875, p. 27 f.
[29] Stewart 1941, p. 289.
[30] Stewart 1941, p. 337; 1942, p. 264.
[31] Schumacher 1877, p. 547 ff.; Lehmann 1927, p. 93 f.; Ellis 1940, p. 43; Wallace & Hoebel 1952, p. 105.
[32] Crabtree & Butler 1964, p. 1 ff.
[33] Purdy 1974, p. 37.
[34] Crabtree & Butler 1964, p. 1.
[35] Crabtree & Butler 1964, p. 3.
[36] Crabtree & Butler 1964, p. 1.
[37] Mandeville 1973, p. 187.

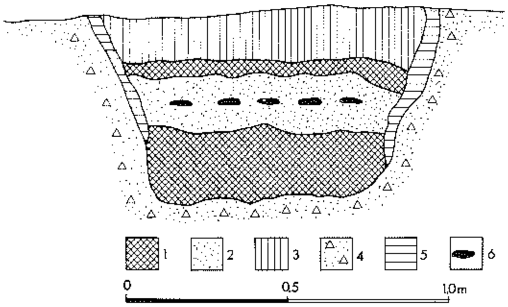


Fig. 1. A section through the pit used for heat treating at the flintknapping field school. Key: 1=sand mixed with charcoal; 2=sand; 3=topsoil; 4=glacial till; 5=red oxidized sand; 6=flint flakes.

nian flint when we attended a course in flintknapping.[38] The procedure was as follows:

A pit 50 cm deep was dug and a 20 cm thick layer of charcoal was produced by burning wood for several hours in the bottom. Sand was then spread above the charcoal. Pieces of flint were spread on this layer of sand, which was then covered by more sand. On this last layer a new fire was lit and allowed to burn for several hours. It was then covered by earth. The filling of the pit was not touched for three days in order to allow for a slow cooling. However, when the pieces were taken up some of them were still so warm that they cracked when exposed to air. When a profile was dug through the pit it could be observed that, despite the mixing of the filling that occurred when the artifacts were dug up, the stratigraphy of charcoal and sand layers could still be distinguished (Fig. 1). Pits filled with layers of charcoal and sand can therefore be an indication of heat treatment at an archaeological site.

Even if the study of heat treatment has been intensive during the past years, it has almost entirely been confined to the USA. In only a few instances have European archaeologists devoted themselves to questions concerning evidence of heat treatment in European prehistory. These studies have primarily dealt with the Late Paleolithic.[39]

[38] We would like to extend our special thanks to Dr. Jeff Flenniken who led the Flintknapping Field School at Washington State University.

[39] Bordes 1969, p. 197; Collins 1973, p. 462 ff.; Inizan *et al.* 1976–77, p. 14 ff.

In order to study if heat treatment was used during prehistory in southern Scandinavia, several tests on flint artifacts from Scania were carried out. In the American material, evidence of heat treatment has been found almost exclusively in connection with the manufacturing of artifacts where pressure-flaking was an important part of the knapping process. Therefore two late Neolithic daggers and a sickle were chosen for testing, as pressure-flaking is the technique performed in the final manufacturing process of these artifacts. Nevertheless, to control if heat treatment was known earlier, a Mesolithic microblade and a Neolithic axe were also tested.

The study was not only limited to finding out if heat treatment has been used or not. An equally important goal was to test methods to prove the presence of heat treatment and to try to establish an easy and inexpensive way of testing this.

2. Changes Resulting from Heat Treatment

Purdy lists 5 factors which determine the physical properties of microcrystalline materials: 1) the size of the quartz crystals, 2) the way the anhedral crystals fit together and affect porosity and fracture, 3) the amount of foreign material, fossil replacements, and other heterogeneities, including flux compounds, present 4) the void spaces, and 5) the crystalline fabric.[40] All but the first of these factors are altered during heat treatment, resulting in changes in the physical properties of the material heated. These property changes can vary with: the material, the temperature applied, the rate of heating or cooling, the evenness of heating or cooling, and the amount of moisture in the heating environment.[41] Several theories to explain the causes of these changes have been advanced, with some measure of consensus being reached.

A. Color change

An obvious change which can occur as a result of heating is a change in the color of

[40] Purdy 1975, p. 134.

[41] Collins & Fenwick 1974, p. 135.

the heated material. This is by no means a foolproof way of determining if a material has been subjected to heat treatment, however. Some materials never change color, while color changes can result from other processes than heating. Also, since any color change resulting from heating affects the whole piece, it may be difficult to recognize that a change has occurred unless the color of the unheated material is known.[42]

Most authors seem to agree that such color change is due to the action of heat on non-siliceous impurities in the material. Mandeville notes that these impurities can be mineralogical or carbonaceous, and that color effects will vary depending on the nature and amount of the impurities.[43] Purdy asserts that such changes occur only in the presence of iron, and thus will not occur if iron is not present.[44] Further, Masson asserts that the intensity of the color change is proportional to the amount of iron in the flint.[45] Several researchers have found that the temperature at which color changes occur is usually lower than the temperature at which the material develops luster,[46] a finding not supported by Inizan's study.[47] Purdy warns against using color change alone as a reliable criterion for indicating heat treatment.[48]

B. Changes in knapping properties

A change which occurs more regularly, and which was no doubt the reason prehistoric man subjected his raw materials to heat, is that which allows greater ease in flaking, especially pressure-flaking, following heat treatment. Don Crabtree discovered this in his pioneer experiments with heat treating,[49] and Mandeville and Flenniken were later able to objectively measure the improved working qualities of chert after heat treatment.[50] Crabtree describes the change as follows:

> It is sometimes difficult to explain this to an inexperienced flintknapper, but the working qualities of the native and heat-treated silica minerals are quite different. The former is tough, relatively inelastic, and will not withstand the necessary pressure, while the latter has greater elasticity and will respond nicely to pressure.[51]

Sollberger and Hester estimate that heat treatment reduces the force necessary to flake stone by about 30 %.[52]

The increased "workability" of silica materials means more concretely that there is a substantial decrease in the applied force needed to produce the desired flakes. This in turn means that larger, longer, more well-controlled flakes can be removed, and that the frequency of step and hinge terminations decreases.[53] It has been suggested that this last property can be used as an indication for heat treatment on otherwise intractible material.[54]

In their experiments with French flint, Inizan *et al.* found an improvement in ease of pressure-flaking in Grand Pressigny flint after it was heated to only 190° for 48 hours. In certain cases it was possible to reach the same degree of improvement in the workability of a material by using a high temperature (300°) for a short time as by using a lower temperature for a long time.[55] They also note that not all materials are improved by heat treatment; some, such as Fontmaure jasper and green dacite from Ténéré, become more difficult to pressure-flake after heat treatment.[56]

Another aspect of this change is that the properties of tools made from heat treated materials will be altered. Sollberger and Hester have noted that heat treatment yields a sharper cutting edge which can be useful for cutting soft material. But at the same time the altered edge becomes more susceptible to breakage when used on hard or tough material.[57] For this reason, thermal alteration is undesirable for raw materials to be made into drills, scrapers, adzes etc. in which a tougher, stronger tool is needed and extreme sharpness of edge is not as important.[58]

[42] Collins & Fenwick 1974, p. 135; Inizan *et al.* 1976–77, p. 14.
[43] Mandeville 1973, p. 183.
[44] Purdy 1974, p. 47.
[45] Masson 1981, p. 22.
[46] Price *et al.* 1974, p. 43; Purdy 1974, p. 47.
[47] Inizan *et al.* 1976–77, p. 18.
[48] Purdy 1974, p. 47.
[49] Crabtree & Butler 1964.
[50] Mandeville & Flenniken 1974.
[51] Crabtree & Butler 1964, p. 1.
[52] Sollberger & Hester 1972, p. 181.
[53] Flenniken & Garrison 1975, p. 129.
[54] Collins & Fenwick 1974, p. 138.
[55] Inizan *et al.* 1976–77, p. 11.
[56] Inizan *et al.* 1976–77, p. 17.
[57] Sollberger & Hester 1972, p. 181.
[58] Crabtree & Gould 1970, p. 194.

Recent attempts have been made to study this problem more thoroughly. In their experiments with sawed flint tiles heated to 350° and 400°C, Bleed and Meier discovered: 1) heat treatment facilitated the removal of relatively large "use flakes" when the tiles were battered in a cement mixer; 2) the flakes removed from the heated tiles were significantly longer than removals from matching unheated control tiles; and 3) heat treatment increased the tendency of flakes to terminate in hinges.[59]

In another study to determine the effects of heat treatment on use-wear on flint tools, Olausson found: Heat treated tools wore more quickly and with more severity than tools which had not been heated. When used in the same fashion and on the same materials, heat treated flakes showed longer microflake removals from use than did non heat treated flakes. The use of the flint tools resulted in more step and hinge flake terminations on the heat treated tools than on the non heat treated tools. Finally, flake scars from microflaking due to use had a shiny surface on flints which had been heat treated, while such surfaces were matt on unheated materials.[60]

C. Loss of water

Experiments by Mandeville, among others, have shown that heat treated materials lose weight at certain temperatures. This is generally explained as being due to the release of water, in various forms, from the material. The weight loss occurring at 100–120°C is thought to be due to the evolution of free or molecular water lodged in interstitial cavities. From 300° to 400°C the water of hydration or chemically bound water is released.[61] But Crabtree has noted that less force is required to detach a flake in freshly mined flint than in untreated, dehydrated flint. The high moisture content seems to reduce brittleness and makes blades more flexible.[62] Patterson and Sollberger concur with Crabtree's observations. They note that water fills the voids and pores in the physical structure of porous flint. The liquid acts as a hydraulic medium to allow a more uniform transmission of force. This in turn permits cleaner, more uniform fracturing, which may be analogous to the effects of heat treating.[63] However Callahan notes that it might take thousands of years for flint to "dry" out so much that it would make any technological difference to the experienced knapper.[64]

These apparently contradictory phenomena are the result of two processes at work here. At temperatures below 100°C, liquid fills available spaces in porous material. This water transmits force more easily in the material and means that "wet" raw material is generally more easily fractured than "dry". Heating to ca 100°C drives out the interstitial water, leaving spaces in which recrystallization can take place.[65] However, recrystallization does not occur until higher temperatures (250°–400°C, depending on the material) are reached. The beneficial effects from this recrystallization for knapping are even greater than those due to the presence of interstitial water below 100°C.[66]

D. Changes at the microcrystalline level

There seems to be a consensus among most researchers today as to what changes occur in the microcrystals of a silica material when it is heated to 250°–400°C. Crabtree was first to speculate on this aspect. His theory has since been modified, but he seems to have been on the right track even as early as 1964:

> Heat treatment causes recrystallization of the more coarsely fibered and coarser micro-granular silica materials, which results in reduced crystal size, a change in luster from dull to greasy, and an increase in the elasticity of the material.[67]

Perhaps the first to advance the hypothesis currently accepted was Mandeville, in 1973. She noted that heat treatment allows fracture to travel across grains, rather than between them.[68] Flint examined through a petrographic microscope at 360x showed the presence of spherical zones 20 to 30 microns in diameter in the raw flint matrix. These intersected the larger quartz granules and encompassed some of the smaller ones. The

[59] Bleed & Meier 1980, pp. 504–505.
[60] Olausson n.d.
[61] Mandeville 1973, p. 197.
[62] Crabtree 1967, p. 14.
[63] Patterson & Sollberger 1979, p. 50.
[64] Callahan 1979, p. 64; *cf.* Pond 1930, p. 21.
[65] Mandeville 1973, p. 199.
[66] Patterson & Sollberger 1979, p. 50.
[67] Crabtree & Butler 1964, p. 2.

zones were more clearly defined in flint annealed at 250°C and were completely absent in that heated to 400°C. These properties were even more apparent when chert samples were examined under a scanning electron microscope. Magnifications of 25,000 showed intercrystalline fracture in raw flint. Samples annealed at 250°C were only slightly altered. Fracture could be seen to be more transgranular and microvoids, barely apparent in the raw material, were well defined. Finally, flint annealed at 400°C showed that microvoids and crystal outlines were still visible. But at this stage fracture was completely transgranular, resulting in a smooth, lustrous scar.[69] Mandeville reasoned that the melting point of SiO_2, the main component of flint, is 1728°C – a temperature well above that which could be achieved under primitive conditions. Therefore, the change which takes place must depend on the non-SiO_2 in the material; that is, impurities in the matrix. The melting point of any impurities expected in chert is too high to explain changes observed at the temperatures used, but the eutectic (melting) point of a combination of minerals is known to be lower than that of any individual members. Photomicrographs of heat treated chert support the theory that melting and fusion take place within the matrix, transforming it from a heterogeneous forest of fiberous structures to one homogeneous mass. The matrix fibers seem to melt and fuse together, incorporating granules and filling intercrystalline spaces to produce a more homogeneous material that fractures like glass.[70] Bonnichsen and Flenniken and Garrison[71] agree in principle with this explanation, while Rottländer's explanation differs slightly. He theorizes that the improved mechanical properties of heat treated flint are due to a certain vitrification welding together the silica scales of which the material is composed. This is probably effected by aqueous solutions under very high pressure which are formed during the heating process.[72]

Mandeville's theory has been expanded upon by Barbara Purdy, who published the results of extensive heat treatment studies a year later. Following numerous tests to elicit what changes occur in Florida chert upon heating, Purdy offered a detailed explanation for these changes. Tests such as X-ray diffraction analysis and petrographic analysis indicated there was no change in the size or orientation of the crystals in chert following heating to 350° or 400°C. But tests to determine specific surface area indicated a 60 % reduction in granular surface area for heated chert. Also, of course, there is evidence of water loss at 100°C and at 350°C. Purdy explains these and other observations in the following manner: The reduction in specific surface area is due to the fact that the microcrystalline surface area has been reduced. This is due in turn to the reduction in intergranular pore radii – the porosity is decreased due to the fusion or intergrowth of grains. Through the removal of interstitial water, the microcrystals are fitted together when certain materials other than SiO_2 serve as fluxes (substances promoting fusion). The fluxes fuse a thin surface film of the cryptocrystals, so that in fracture, crystal boundaries are no longer interfering with the removal of flakes.[73]

Thus,

> . . . crystal boundaries may be a disturbing influence when attempting to predict fracture. Therefore, the more glass-like the material, the more predictable the fracture. Heated cherts are more glass-like and fractures are not only more predictable but easier to execute.[74]

Further work by Weymouth and Mandeville suggests that such enhanced transgranular fracture is due to microcracks or local strains which effectively break up the crystals in the material. This could be due to heating and loss of water, which could then lead to transgranular fracture.[75]

This theory that impurities in the silica material serve as fluxes to more closely fuse the microstystals of the material seems to be the most likely explanation for the changes which occur in flint-like materials during heat treatment. The resulting quality of a more predictable, more glass-like fracture was undoubtedly the effect sought by prehistoric flintknappers when they subjected their raw materials to heat.

[68] Mandeville 1973, p. 198.
[69] Mandeville 1973, p. 190.
[70] Mandeville 1973, p. 199; *cf.* Figs. 3–7b.
[71] Bonnichsen 1977, pp. 186–187; Flenniken & Garrison 1975, pp. 128–129.
[72] Rottländer 1976, p. 55.
[73] Purdy 1974.
[74] Purdy 1974, p. 46.
[75] Weymouth & Mandeville 1975, pp. 66–67.

3. Means of Testing whether Materials have been subjected to Heat Treatment

Some of the possible ways of determining whether stone has been heat treated have been alluded to above in the section dealing with what changes result when heat is applied. In spite of concentrated and systematic work by many researchers, there is as yet no test which can establish with 100 % certainty if a prehistoric artifact has been intentionally heat treated. However, there are numerous tests which can give some indication, so that a combination of positive results from several tests can establish the likelihood of the presence or absence of heat treatment. These tests and indications will be discussed below, beginning with those which do not require special equipment, and ending with those which do.

A. Color change

As was noted above, impurities may cause color changes in silica materials from about 250°C. However, there are several possible error sources in this test. Purdy notes that this color change will not occur if iron is not present in the material. She also notes that color change occurs at a lower temperature than the change in knapping properties, so that change in color is not a reliable indication of purposeful heat treatment by prehistoric man.[76] In rebuttal to Purdy's observation that the presence of iron is required for a color change to occur, Rowlett *et al.* can be cited:

> Apparently when Stone Age man baked his flints, often the process of protecting them from thermoclastic damage – such as building a fire over flint protected by a sand or earthen cover – would have produced a reducing atmosphere, so that even iron-rich siliceous materials would have fired grey.[77]

Collins and Fenwick point out that the recognition that a material has undergone a change in color depends on the researcher's familiarity with the normal colors of the raw material. They also remark that color changes may tend to increase with increased temperatures, but that this is not true of all material.[78]

Thus a change in color can be taken as a positive indication for the application of heat, but its absence need not mean heat was not applied to the material in question.

B. Lustrous flake scars

One of the best known and most obvious results of heat treatment is a greasy luster on surfaces flaked subsequent to heat treatment. The observation of this luster was what first triggered Don Crabtree's pioneering experiments with heat treatment.[79] This luster, variously described as greasy, glossy, waxy or vitreous, was evident on all surfaces of the present archaeological samples flaked after heat treatment, but was not observed on surfaces flaked before heat treatment. This suggested that the samples had not been heated prehistorically; a conclusion supported by our subsequent analysis. Although Collins and Fenwick report that this change usually occurs at temperatures over 300°C,[80] Inizan *et al.* found that the minimum temperature for producing luster varied with the material. They discovered that a temperature of 160°C was sufficient to produce luster on Bergerac flint, while quartzite remained unmodified even after being subjected to 600°C.[81] The amount of luster seems to be linked to the grain size of the heated material – a coarser material shows less luster and requires a higher temperature to produce luster.[82]

For the archaeologist, the patterned distribution of lustrous and non-lustrous flake scars on an artifact can provide strong evidence for intentional heat treatment followed by further flaking.[83] It was such evidence that led Bordes to assert that heat treatment was being performed by the Solutreans some nineteen thousand years ago. Bordes found patterns of lustrous and non-lustrous flake scars on a laurel leaf blade from Laugerie-Haute, an Upper Solutrean

[76] Purdy 1974, p. 47.
[77] Rowlett *et al.* 1974, p. 42.

[78] Collins & Fenwick 1974, p. 135; *cf.* Masson 1981, p. 22.
[79] Crabtree & Butler 1964, p. 1.
[80] Collins & Fenwick 1974, p. 137.
[81] Inizan *et al.* 1976–77, p. 10.
[82] Masson 1981, p. 24.
[83] Collins & Fenwick 1974, p. 137; Inizan *et al.* 1976–77, p. 1.

site from southern France.[84] Collins pursued the evidence further, and discovered that about 1 % of the total flakes and implements from Laugerie Haute Ouest showed evidence of heat treatment.[85] He found evidence for heat treatment in the Upper and Final Solutrean, and possibly as early as the Middle Solutrean.[86]

Some caution is required for this test, too, however. Collins and Fenwick note that some cherts never evidence this greasy luster.[87] Sollberger and Hester caution that only a recently-factured surface should be used to identify heat treatment, since luster can also be caused by such processes as patination, weathering, and silica polish. They suggest that it is advisable to compare archaeological specimens with freshly-flaked raw material from the area, in order to avoid such errors.[88]

It should be emphasized that random areas of luster probably represent accidental exposure to heat rather than intentional heat treatment. Given the ubiquity of hearths on prehistoric sites, it is not surprising that flint tools should have come into frequent contact with heat. Suspecting that those who knapped the poorer quality Kristianstad flint may have improved the quality of the material by heat treatment, we examined pressure-flaked Late Neolithic artifacts from the site of Månsagård in eastern Scania.[89] A few of the artifacts showed lustrous surfaces, but these occurred randomly. A pressure-flaked dagger fragment, on the other hand, showed no evidence of lustrous flake scars. One preform bore potlid fractures characteristic of heat damage. This evidence led us to conclude that the makers of these artifacts had not availed themselves of the improvement in raw material quality which heat treatment provided. It is dangerous to assert on the basis of a few lustrous flake scars that intentional thermal pretreatment was being practiced. Cases of non-lustrous scars on heat treated cherts, and of lustrous scars on non-heat treated materials, are known.[90] For instance, flint which has been subject to aeolian action may evidence a luster which could be confused with heat treatment luster, although under the microscope the two are easily differentiated.[91] The luster caused by heat treatment should not be confused with polish, as there is no aspect of abrasion involved in its formation.[92]

C. Changes in patination processes

It seems that in some cases heat treatment can alter the speed at which silica materials become patinated. Collins and Fenwick attribute this to the fact that the impurities in the stone may be altered during heat treatment, retarding the rate of patination. However, Purdy contends that heat treated specimens of Florida chert become patinated faster than non-heat treated cherts.[93] She has also recently discovered that heat treated specimens weather more quickly than raw ones. Based on this, she suggests that the presence of differential weathering observed on specimens from the same provenience may be an indication that some of the specimens were heat treated.[94] On the other hand, Rottländer claims that the formation of patina is not influenced by heat treatment.[95] Because such uncertainty remains, this seems to be a rather unreliable way of checking for heat treatment.

D. Heat damage

Collins and Fenwick advise that evidence of heat damage is not a reliable indicator of purposeful heating.[96] While this is true, it is nevertheless worthwhile to note that the presence of heat damage on materials does indicate that they have come in contact with heat, even though this may have been accidental. Experiments by Price *et al.* showed that changes upon heating took place in the following order, depending on the intensity and duration of the heating: 1) color change, 2) potlidding or cracking, 3) a complete loss of structural water resulting in white opacity and porcelain texture in the remaining de-

[84] Bordes 1969, p. 197.
[85] Collins 1973, p. 465.
[86] Collins 1973, p. 462.
[87] Collins & Fenwick 1974, p. 137.
[88] Sollberger & Hester 1972, p. 182; Gregg & Grybush 1976, p. 192.
[89] Strömberg 1955.
[90] Inizan *et al.* 1976–77, p. 2; Masson 1981, fig. 14.
[91] Masson 1981, p. 75.
[92] Masson 1981, p. 24.
[93] Collins & Fenwick 1974, p. 136.
[94] Purdy & Clark 1979, p. 20.
[95] Rottländer 1976, p. 55.
[96] Collins & Fenwick 1974, p. 136.

hydrated silica.[97] The phenomena indicative of heat damage include potlid fractures, splinters lacking a bulb of force, "crenated" fracture, and crazing.[98] Such signs may be clues to attempts at heat treatment which failed, and thus their presence should be noted when one is searching for evidence of heat treatment archaeologically.

These are the major indications which an archaeologist can note without the aid of instruments when looking for evidence of heat treatment. The indications become more reliable when they can be compared against the appearance of the material in its raw state, and when several of the tests give a positive result. The archaeologist can also examine his site for evidence of heat treatment pits. These can vary in appearance, but the existence of a pit showing evidence of fire at the bottom and at the top of the pit, with sand between and perhaps even a few remaining pieces of flint in the sand layer, is strong evidence for heat treating (Fig. 1).[99]

There are also more cumbersome tests which can be run when the proper equipment is available. While none of these tests can give 100 % assurance of heat treatment, there are several which seem to be quite reliable, although still in need of refinement.

E. Loss of water

As was described above, experiments have shown that heat treated materials experience weight loss at different stages of the heating process. The first to be lost is free or molecular water lodged in interstitial cavaties. This evaporates at 100–200°C. Between 120° and 300°C the weight remains stable, but between 300° and 400° the chemically bound water is released. Finally, at temperatures of 600°–700°, the decomposition of the carbonates takes place.[100] However, such weight loss does not seem to be a particularly advantageous means of establishing heat treatment, for several reasons. The most obvious is that, as an archaeologist, one would have no way of telling whether weight loss had occurred without a control sample for comparison. Quantities of water vary from material to material, so that it is necessary to get control specimens in order to establish what amounts of water are normal before heat treatment.[101] Purdy has also discovered that weight loss is not a reliable criterion because heated specimens take on moisture again.[102] Thus loss of weight is one of the least effective tests for heat treatment of prehistoric materials.

F. Compressive tests

Purdy used a 300,000 lb capacity Riehle Universal testing machine to test what happened to heated and unheated stone when subjected to compression. She found that when materials are heated to 400–500°C for sustained periods and removed while hot, their compressive strength is reduced by 40 %. But when samples are allowed to cool slowly in the oven after heating, there is an increase in strength of 25 % for obsidian and 40 % for High Springs Chert.[103]

G. Point tensile tests

Tests of the tensile strength of heated and unheated materials yielded the following results: Heating to 400°C for 24 hours and removing immediately from the oven reduced by 45 % the force needed to break the material. At different temperatures and for different materials, one sees a greater reduction in strength with an increase in temperature.[104] Collins and Fenwick also noted that tensile strength is consistently reduced by heating.[105] Both this and the preceeding test require a basis for comparison between heated and unheated materials. If one does not have access to raw materials known to be unheated, one can presumably proceed, as we have, by taking two samples from the artifact to be tested. One is heated, the other is kept as a control, and if the tensile strength shows reduction following heating, it is assumed that the artifact was not previously subjected to heat. The tensile strength test does seem to be a reliable test, in any case.

97 Price *et al.* 1974, p. 43.
98 Purdy 1975.
99 See for example Shippee 1963, p. 272; and Grantzau 1954, p. 35, for possible examples.
100 Mandeville 1973, p. 197; Purdy 1974, p. 45.
101 Collins & Fenwick 1974, p. 137.
102 Purdy 1974, p. 52.
103 Purdy 1974, p. 48.
104 Purdy 1974, p. 49.
105 Collins & Fenwick 1974, p. 137.

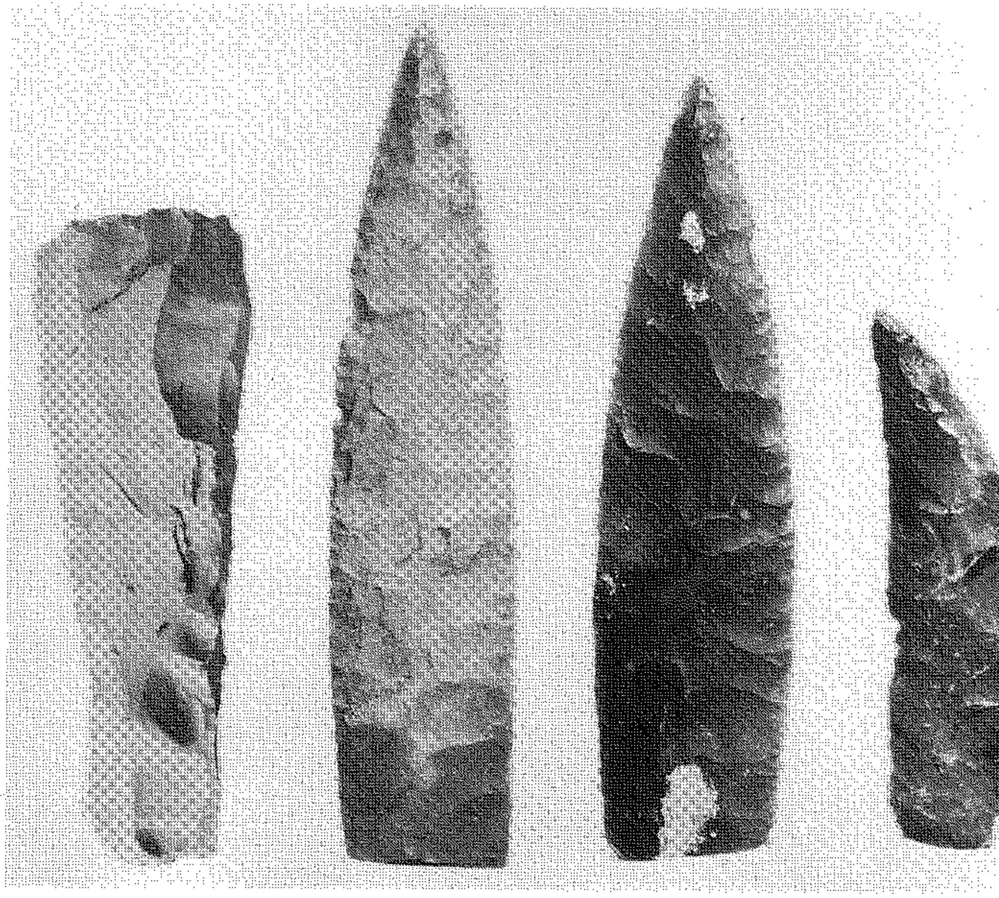


Fig. 2. Four of the objects tested for heat treatment. L to R: the middle Neolithic thick-butted axe, the 2 fragmentary late Neolithic daggers, and the fragmentary late Neolithic sickle. Scale 2:3.

H. Petrographic analysis

Crabtree subjected thin sections of heated silica mineral specimens to optical examination. He found relic areas which he identified as microscopic islands of the original crystalline structure of the mineral.[106] However, Purdy's results contradict this somewhat. She saw no significant difference between heated and unheated specimens at 100x magnifications, and found no change in the size of the individual crystals or their orientation when heated to 350–400°.[107] Purdy's results are more consistent with those discussed in the section dealing with the microcrystalline changes, and indicate that petrographic analysis is not a reliable means of identifying heat treatment.

[106] Crabtree & Butler 1964, p. 2.
[107] Purdy 1974, p. 50.

I. Differential thermal analysis

Mandeville found that by comparing the firing curves in an oxygen and in a nitrogen atmosphere, she could detect the existence of termal pretreatment and give a rough estimate of the temperature at which the specimen was annealed.[108] Purdy also found that differential thermal analysis indicated peaks at 100° and at 350–600°C, roughly corresponding to the two critical temperatures for water loss.[109] If the method is as reliable as it seems to be from Mandeville's results, it is probably worth pursuing.

[108] Mandeville 1973, p. 190.
[109] Purdy 1974, p. 50.

J. X-ray diffraction analysis

Purdy found no consistent differences, indicating that no change in the crystal lattice occurs with heat treatment, when she applied X-ray diffraction analysis to her specimens.[110] Collins and Fenwick concur, noting that there is apparently little or no change in materials in the heat range of 300°C.[111] However, much more encouraging results were reached by Weymouth and Mandeville. Tests on 8 samples of chert heated to different temperatures showed in many cases that the effective crystal size decreased after heating to 400°C, and in all cases but one such decrease was evident after heating to 800°C. They predicted that after further refinements, the method may be used in the future for testing the presence of heat treatment.[112]

K. Fission track analysis

Collins and Fenwick report that temperatures approaching 600°C may obliterate fission tracks in materials. One can then use techniques of fission track dating to determine if such heating had occurred. They note however that the technique can probably only be used on homogeneous material such as obsidian, and that it cannot distinguish between accidental and intentional heating.[113] An additional objection which can be raised is that for most materials, temperatures lower than 600°C were sufficient to obtain the desired results;[114] apparently lower temperatures would not be sufficient to remove existing fission tracks. This method thus does not seem to be a very advantageous one for the present purposes.

L. Thermoluminescence

A promising technique for identifying previous heating is that of thermoluminescence. Heating to sufficient temperatures in prehistory sets the equivalent dose to zero. Rowlett *et al.* conducted an experiment in which the TL of two series of baked and unbaked siliceous material were measured when heating the samples to 400°C. One of the control series was a sample of chert baked in the laboratory, the other was of archaeological material. The control series showed it was easy to distinguish between baked and unbaked samples of the same chert.[115]

Techniques of TL can also be used for dating when flints were heated, applying similar techniques as those used on pottery.[116] Wintle and Aitken have recently applied TL dating to burned flints from Terra Amata, arriving at dates of 214,000 and 244,000 B.P.[117] TL may thus provide a means of dating burned flints older than the limits of C14 dating but younger than those datable by the potassium-argon method.[118]

There is some disagreement about the applicability of TL for discerning prehistoric heat treatment, however. While Melcher and Zimmerman claim that 250° is sufficient for setting the equivalent dose to zero,[119] Masson claims 380°C as the minimum temperature required.[120] Masson's results, and those of Inizan *et al.*, have shown that for most flints the minimum temperature required for heat treatment is lower than what is required for TL analysis.[121]

A related method which may be more reliable for discovering the presence of heat treatment is being developed by Robins. Heated flint emits a characteristic "ESR signal" which is absent in unheated flint. This signal is stable over an indefinite period of time.[122]

Thus it would seem that while more work must be done to define its uses and its limits, the method of thermoluminescence analysis may be one of the most unequivocal tests to determine if (and when) stone has been subjected to high temperatures in the past. A disadvantage with the method is that thin sections of the flint are necessary, which may be undesirable for the archaeologist. Of course, this test alone cannot differentiate between intentional and accidental heating, but it is not difficult to deduce this from other evidence.

110 Purdy 1974, p. 50.
111 Collins & Fenwick 1974, pp. 139–140.
112 Weymouth & Mandeville 1975, pp. 66–67.
113 Collins & Fenwick 1974, p. 136.
114 Inizan *et al.* 1976–77.
115 Rowlett *et al.* 1974.
116 Seeley 1975; Wintle 1980.
117 Wintle & Aitken 1977, p. 124.
118 Göksu *et al.* 1974, p. 651.
119 Melcher & Zimmerman 1977, p. 1361.
120 Masson 1981, p. 74.
121 Masson 1981, p. 74; Inizan *et al.* 1976–77.
122 Robins *et al.* 1978, p. 703; Garrison *et al.* 1981.

M. Scanning electron microscope

The changes at the microcrystalline level which heat treating causes can be observed at magnifications of at least 1000 diameters under the scanning electron microscope. Comparisons between raw and heated specimens at these magnifications seem to yield fairly certain results. Because of this, and because we had access to a S.E.M. (TL equipment was not nearly as accessible) we used this method for our determinations.

As is evident in Figures 3, 4a, 4b, 6b, 7a, the fresh surface of unheated specimens differs from that on heated ones. In the unheated specimens, the individual grains look like bread crumbs (Fig. 3). Some fracturing has occurred through the individual grains, but more frequently fracture passes around the grains. After heating the grains are split, and fractures continue on passing through interstitial areas which are now more firmly cemented.

In other words, when fracture occurs it alternately splits and passes through succeeding crystals and intercrystal areas in its path until it terminates. This accounts for the smooth surface in the heated specimens.[123]

It is also sometimes possible to detect the loss of certain inclusions after heating.[124]

There are a few drawbacks with this test. One is that the interpretation of the results is subjective. It is left to the viewer's judgment to decide whether there is a significant difference between surfaces of heated and unheated specimens. We found that the surfaces themselves were by no means homogenous, so that in places the surface of an unheated flake could look quite smooth, and conversely some areas of heated surfaces were much rougher than others.[125]

Another limitation, which also applies to many of the analyses described above, is that the test is destructive of archaeological specimens. The samples required for the S.E.M. are admittedly small (up to 0.5 mm in diameter), but they nevertheless require alteration of the archaeological specimen. But aside from these objections, the method is fairly simple and straightforward.

Thus there are numerous approaches open

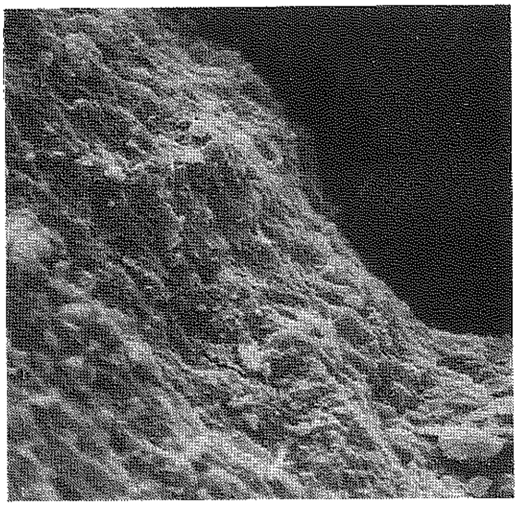


Fig. 3. The unheated flake of freshly mined Senonian flint. The character of the surface is typical for unheated flint. Magnification 2000 X.

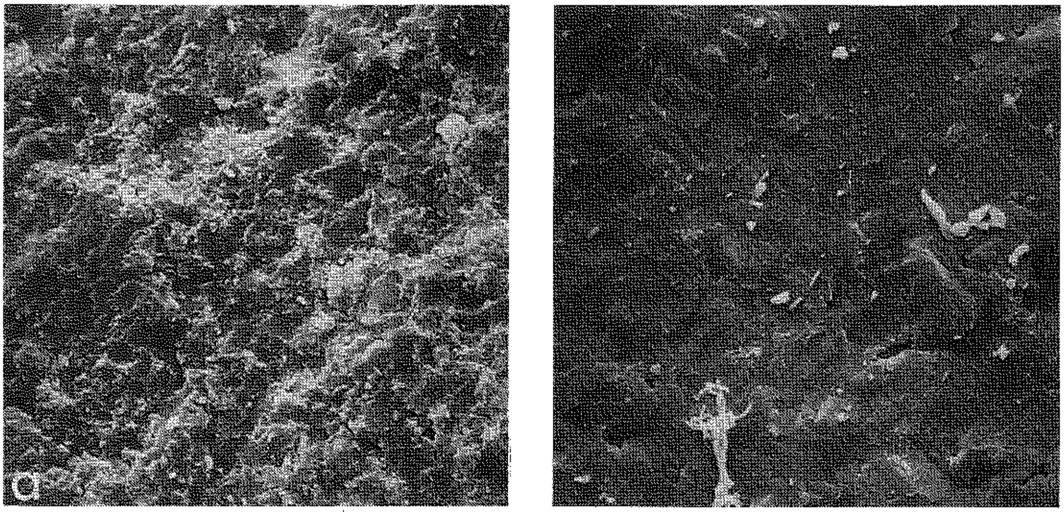
to the archaeologist who wants to know if artifacts in his collection have been subjected to heat treatment. By themselves, none of the tests can give a positive or a negative answer with absolute certainty, but a combination of several tests can often provide an accurate answer. When possible, TL analysis, tensile strength tests, and S.E.M. examination should be undertaken, as these are the tests presently available which yield the most reliable results.

4. Analytical Procedure

Because different materials react in different ways to the application of heat,[126] it was first necessary to determine what conditions of time and temperature could be used for heat treating the flint of which the archaeological specimens we wanted to test were made. Although Rottländer claims that such flint cannot be heat treated without becoming white and cracking,[127] tests of Senonian flint taken from the location of the Kvarnby mines (known to have been used prehistorically)[128] indicated that temperatures of 400°C caused easier flaking and lustrous flake scars on such flint.

[123] Purdy 1974, p. 51.
[124] Collins & Fenwick 1974, pp. 138–139.
[125] Compare Figs. 4a, 4b, 6a, 6b, 7a and 7b and Collins & Fenwick 1974, figs. 3–5; Mandeville 1973, figs. 9–19; Purdy 1974, figs. 11–12.

[126] Inizan *et al.* 1976–77.
[127] Rottländer 1980, p. 29.
[128] Olausson *et al.* 1980.



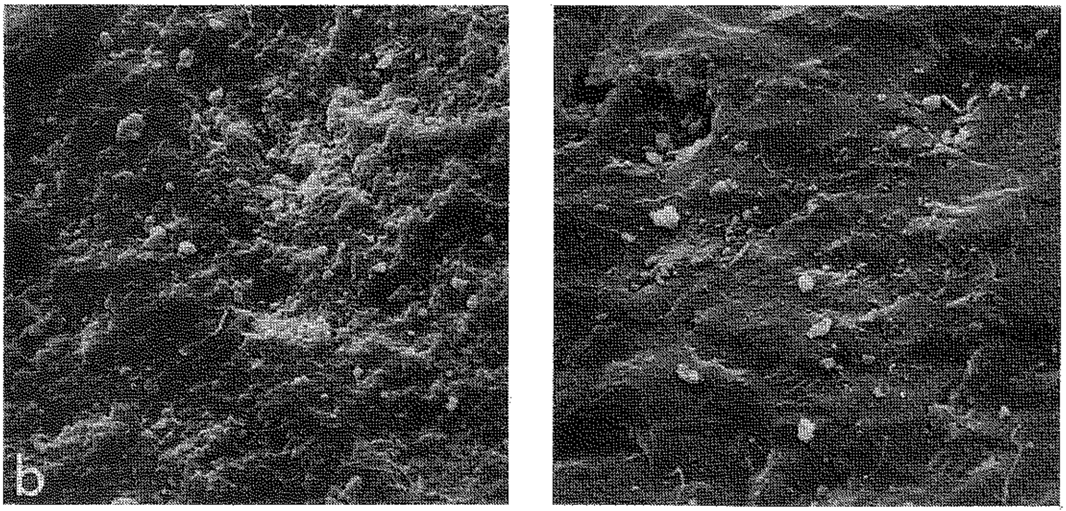


Fig. 4a. S.E.M. photographs of samples taken from the late Neolithic sickle. To the left is a fresh surface from the non-heated flake, showing the crumbly structure which is characteristic of raw flint (*cf.* Fig. 3). To the right is a fresh surface from the heat treated flake, in which the more vitreous character of the heat treated flint is evident. The structural change which followed modern heat treatment indicated that the sickle was not previously subjected to heat treatment. Comparison of these samples with those from the axe (Fig. 7a), the microblade (Fig. 4b), and the dagger (Fig. 6b) indicates that the gloss observed on the edge of the sickle has not affected the inner structure of the flint, nor was it due to the effects of previous heat treatment. Magnification ca 2000 X.

Fig. 4b. Photographs of samples taken from a Mesolithic microblade. L: The unheated surface. R: The heated surface. It is evident that the microblade has not been heated previously. Magnification ca 2000 X.

We were interested in learning if four specific Scandinavian flint artifact types had been subjected to heat treatment prior to final flaking: thick-butted axes, daggers, and sickles from the Neolithic, and microblades from the Mesolithic. Because of the delicate nature of the pressure-flaking on late Neolithic daggers and sickles, we strongly suspected these had been heat treated,[129] although no lustrous flake scars were visible on their surfaces. Likewise one could imagine

[129] Inizan *et al.* 1976–77, p. 17.

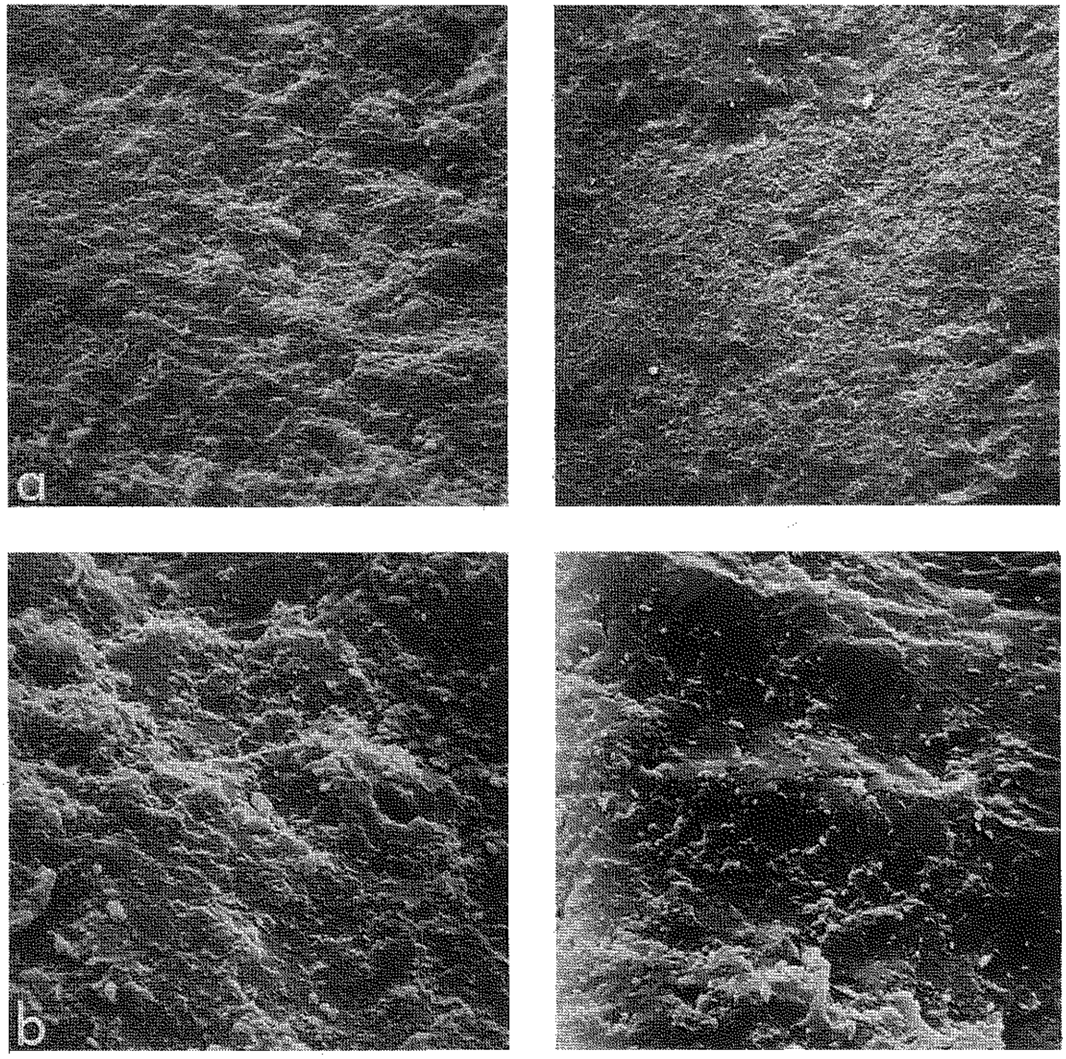


Fig. 5a. Photographs of samples taken from the first late Neolithic dagger. On the left is the fresh surface on a flake taken directly from the dagger, on the right the fresh surface of a flake which we heat treated. Comparison of this figure with Figs. 4a, 4b, and 6b shows that the contrast between the two surfaces is very slight, and in neither case is the surface characteristic of either a heated or an unheated surface. Magnification ca 2000 X.

Fig. 5b. Another spot on the same flakes as are shown in Fig.5a. L: The unheated flake. R: The heated flake. Here again the contrast is slight, and the flake which we did not heat gives the appearance of having been heated previously. Magnification ca 5000 X.

that heat treatment would have aided in removing microblades. Because heat treatment makes the edge more brittle, however,[130] we did not expect that Neolithic man had heat treated his axe blanks.

It is necessary to have a fresh surface of a raw material for comparison with that from a heated material to be able to identify heat treatment under the scanning electron microscope. Because we wanted to be certain that differences in raw material could not be the cause of any differences in surface appearance under the S.E.M., we proceeded as follows: We assumed that the changes caused by heat treatment are permanent[131]

[130] Olausson n.d.

[131] Inizan *et al.* 1976–77, p. 10.

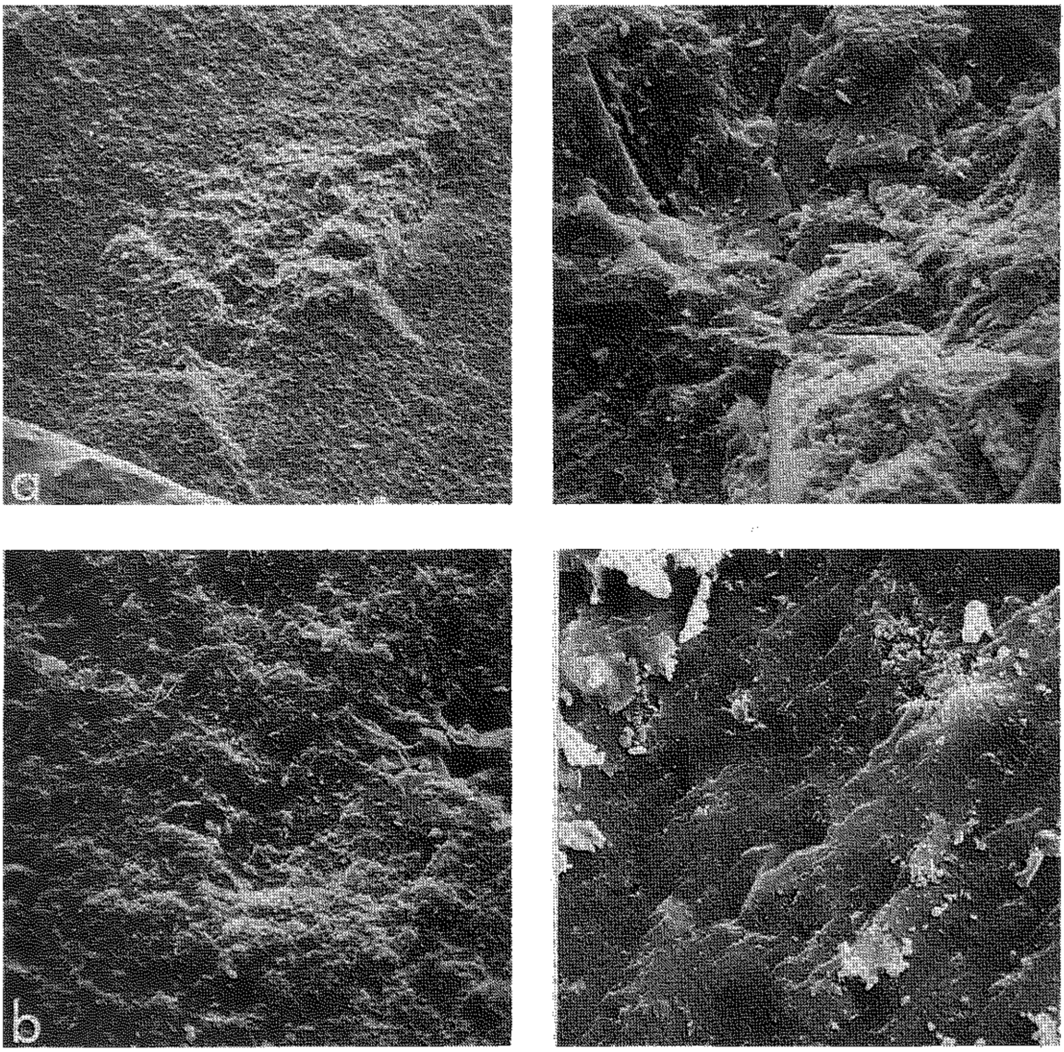
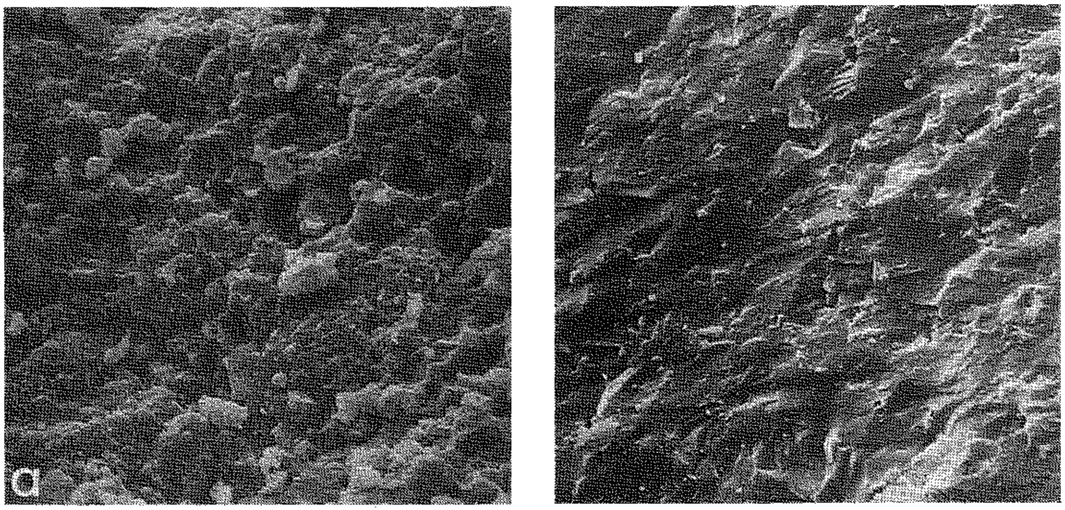


Fig. 6a. S.E.M. photographs of the surface of the unheated flake taken from the second dagger. The heterogeneity of the surface is evident here. Fig. 6b is a magnified view of the more homogeneous surface on the flake. L: Magnification 200 X. R: Magnification 2000 X.

Fig. 6b. The flakes from the second dagger. L: Fresh surface on an unheated flake; R: Fresh surface on the heat treated flake. Here the results agree with those from the thick-butted axe, the sickle, and the microblade, indicating that the dagger had not been previously heat treated. Magnification 2000 X.

and that more than one treatment will not further alter the microscopic appearance of the flint.[132] We pressed off two small flakes from the following objects (Fig. 2): a thick-butted axe, a sickle and a dagger from the Neolithic, a Mesolithic microblade, and one flake from a piece of raw Senonian flint from Kvarnby. At this stage we noted that even these fresh flake scars were not lustrous, which made us suspect that none of the objects had been heat treated. One of each of these pairs of flakes, and the raw flake,

[132] We later tested this assumption and found it to hold true (See p. 22 and Fig. 7b). Brink found that reheating chert samples which had presumably already been heated dehydrated them, causing cracks. However the damage may have been due to the high temperature he used (500°C) rather than to the effects of reheating (Brink 1978, pp. 24–25).



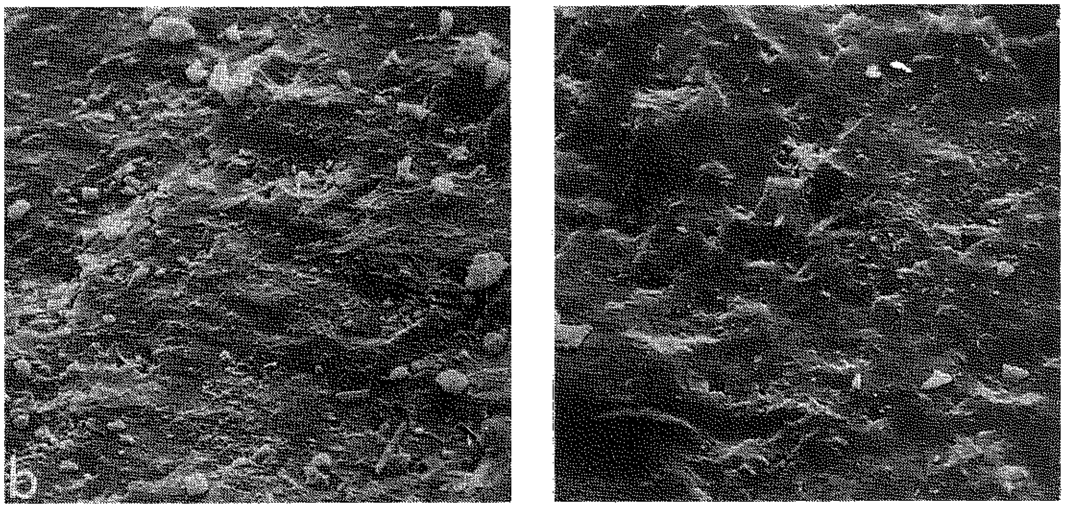


Fig. 7a. S.E.M. photographs of samples taken from a Neolithic thick-butted axe. L: Fresh surface on an unheated flake. R: Fresh surface on a heat treated flake. It is evident that the axe has not been heat treated previously. Magnification ca 2000 X.

Fig. 7b. S.E.M. photographs of flakes taken from the same thick-butted axe as shown in Fig. 7a. These flakes have been subjected to modern heat treatment two successive times. To the left is a surface which was flaked after both the first and second heat treatments; the photograph to the right shows a surface flaked after only the second heating. The photographs illustrate that multiple heat treatments do not appreciably alter the structural change achieved after initial heat treatment. Magnification 2000 X.

was kept as a control, and the other was subjected to heat treatment using procedures based on our preliminary experiments. We reasoned that, if the artifacts had been heat treated prehistorically, the appearance of the control flakes should match that of the flakes heat treated by us; conversely differences such as Mandeville (1973) or Purdy (1974) show should indicate that the control flakes (and thus the artifacts from which they were taken) were raw and had never been subjected to heat treatment.

One of the flakes from each artifact was buried in a sand bath and heated in an oven according to the following schedule:

8:00	samples placed in a cool oven, temperature raised to	100°C
9:00	temperature raised to	200°C
10:00	,, –	250°C
11:00	,, –	300°C
12:00	,, –	350°C
15:00	,, –	400°C
17:00	Oven turned off 36 hours later the flakes were removed from the cool oven.	

We then pressed marginal chips off these heat treated flakes, in order to provide the necessary fresh surface for S.E.M. analysis. These fresh scars were lustrous, indicating the heat treatment had succeeded. The five "raw" flakes and the four heat treated flakes were then mounted with glue on the S.E.M. specimen mounts, with their freshly flaked surfaces up. They were cleaned with acetone to remove dust and glue, then covered with a carbon/gold combination in a vacuum evaporator. The raw and heated surfaces were then examined under the S.E.M. at ca 2000 and ca 5000 magnifications.

The results of these tests, while clear for the axe, sickle and microblade, were ambiguous for the dagger (Figs. 5a, 5b). We also wondered if our assumption, that heat treating more than once will not alter the surface appearance, was valid. With this in mind, we conducted a second series of tests.

Two samples from another dagger were prepared in the same way as above. Additionally, two new chips were removed from the thick-butted axe we had already tested, since we now knew it had not been heat treated previously. These two axe chips were subjected to heat treatment twice, following the same schedule as above. One of the axe chips was pressure-flaked at the same place after both the first and the second treatments; the other was flaked only after the second heating. The dagger and axe samples were then mounted and examined as above.

In connection with our observations about Kristianstad flint (p. 13), we also performed an experiment to determine if heat treatment improved the working quality of this coarser material. Accordingly, we subjected 3 flakes of this material to heat treatment. We suspected that such high temperatures as we had used for the Senonian flint were unnecessary, and instead used the following heating schedule:

8:00	samples placed in a cool oven, temperature raised to	150°C
9:00	temperature raised to	250°C
10:00	,, –	350°C
16:00	oven turned off and allowed to cool to room temperature	

Subsequent pressure-flaking of the flakes revealed lustrous flake scars and greater ease of flaking, indicating that the lower temperature had been sufficient to heat treat this variety of flint.

5. Results

Comparison of the structure of the samples at 2000 and 5000 magnifications from the first series of tests showed unequivocally that three of the four objects had not been subjected to heat treatmeant in the past (Figs. 4a, 4b, 7a). Tests run on the second dagger also showed that this object had not been previously heat treated, although results from the first dagger were ambiguous (Figs. 5a, 5b, 6a, 6b). We found that the structure of the axe flakes was not altered after two successive heat treatments, and the surface which was flaked after both the first and second heating resembled that which was flaked after only the second heating (Fig. 7b). Finally, comparison of the raw and heated surfaces of fresh flakes taken from the glossy edge of the sickle were in general identical to raw and heated fresh flakes taken from the surfaces of the other objects (Fig. 4a). It would thus seem that the presence of sickle gloss has no effect on the inner structure of the material either before or after heat treatment. These results also indicate that the gloss visible on the sickle edge was not due to heat treatment.

6. Discussion and Conclusions

The analysis described above yielded the clear result that the five flint artifacts examined by us have not been heat treated. However, it is not possible solely on the basis of our preliminary results to rule out the possibility that heat treatment was practiced in Scandinavian prehistory. Such a statement requires the analysis of a number of flint artifacts with a larger distribution in space as well as in time. For such a comprehensive analysis the methods for demonstrating heat treatment discussed above could be used.

There are several possible explanations as to why heat treatment may not have been used in Scandinavia. The first is that the knowledge of heat treatment might never have reached Scandinavia. In Western Europe there is no concrete evidence, apart from some simple ocular and therefore uncertain studies, for the use of heat treatment in prehistoric times. As long as there are no more conclusive indications of heat treatment, the occurrence of the process is not satisfactorily proved in Europe, in spite of the ethnographic accounts showing that the method was practiced almost worldwide in more recent times.

Another, more practical reason, might lie in the physical change caused by heat treatment. The process causes flint to become easier to knap; but on the other hand, the finished product becomes more brittle and consequently less durable. The flint we analysed is a homogeneous variety from the Senonian period, and it is considered by flintknappers to be one of the best silica materials in existence for manufacturing flint artifacts requiring an advanced knapping process. The benefits from the heat treatment of this high quality flint may not have been so worthwhile to a trained flintknapper so as to counteract the negative effect of reduced durability in the resulting tool.[133] However it does seem likely that the artisans who made their tools from Kristianstad flint from eastern Scania would have used heat treatment had they known of the process, since this material is of much lower quality and can be improved by heat treatment. We did not think it was necessary to use S.E.M. tests of whether this technique was used prehistorically on tools made from Kristianstad flint, since our examination of pressure-flaked tools made from such flint did not show any evidence of conscious heat treatment in the form of patterned lustrous flake scars (p. 13). Moreover, the North American examples of heat treatment are often artifacts thought to be used as spearheads, which were exposed to quite another kind of damage than the daggers and sickles from Scandinavia.

[133] Callahan, 1980, p. 24.

Acknowledgement

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Larsson has written sections 1 and 6.
Olausson has written sections 2–5.

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