
Inefficient practice of flint heat treatment at Hasankeyf Höyük: An anti-functional view

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Abstract:

This paper investigates the heat treatment of flint practiced at the Neolithic site of Hasankeyf Höyük in southeast Turkey. It does not involve petrographic or geochemical analysis to identify the physical and chemical evidence of heat treatment but aims to understand cultural aspects of the use of ancient lithic technology, using heat treatment as a case study. Heat treatment is a lithic production technique in which siliceous rocks are heated by controlled fire in order to improve their flaking quality. Archaeological evidence of heat treatment is seen all over the world, and numerous studies have contributed to the better understanding of this technique. However, what is particularly intriguing in the case of Hasankeyf Höyük is that there are many flint artefacts which were apparently overheated and unusable due to the frequent failure in achieving successful heat treatment. On the other hand, experimental studies using an electrical furnace and open fire show that once the appropriate heating time and temperature are learnt, the heat treatment of local flint at Hasankeyf Höyük is an easy process and does not require high technical skill. It is therefore suggested that heat treatment at this site was exercised along non-economic principles by people who were not very keen on improving technological efficiency, even when they could have easily done so.

Keywords: heat treatment; chert; experimental study; inefficient technology; Neolithic

1. Introduction

Heat treatment of lithic raw materials is a popular research subject in which archaeological science has played an important role. In the 1960s and 70s numerous studies addressed this issue, particularly in North American archaeology, where archaeological science was favoured by New Archaeology as one of the methods that served Middle Range Theory (*e.g.*, Crabtree & Butler 1964; Flenniken & Garrison 1975; Mandeville 1973; Purdy & Brooks 1971; Robins *et al.* 1978; Weymouth & Mandeville 1975). Since then, a range of studies have been carried out globally involving various petrographic and geochemical analyses concerning the physical alteration of a rock's microstructure (*e.g.*, Beauchamp & Purdy 1986; Domanski *et al.* 1994; Domanski & Webb 1992; Schindler *et al.* 1982). Also, many experimental studies particularly concerning optimal heating conditions have been carried out (*e.g.*, Bleed & Meier 1980; Griffiths *et al.* 1987; Inizan & Tixier 2000). More



recently, the studies of heat treatment using newly developed analyses for Palaeolithic sites in South Africa have drawn our attention to its technological evolution by early modern humans.

Probably because of this research background, heat treatment of lithic raw materials is often approached from a utilitarian viewpoint, which tends to regard it as a technological innovation that enabled the more efficient production of more effective tools. However, such a perspective on ancient lithic technology cannot always be sustained. In practice, the conduct of lithic technology is often directed by cultural or social factors rather than economic or technological conditions. The case of flint heat treatment at the Neolithic site of Hasankeyf Höyük in southeast Turkey is a good example. The archaeological evidence of lithic assemblage at this site demonstrates frequent failure in the practice of heat treatment, while experimental studies suggest that heat treatment using local flint is not a difficult process. (Note that in this paper, the term “flint” is used synonymously with “chert” and does not specifically refer to materials from Cretaceous chalk deposits.) It is thus supposed that flint heat treatment was exercised at this site rather inefficiently by people who did not care about the improvement of economic and technological efficiency.

To confirm this assumption, this paper examines flint heat treatment in the local context of Hasankeyf Höyük based on experiments using an electrical furnace and open fire. Unlike other studies, the present paper does not involve petrological or geochemical analysis. Instead, the emphasis is placed on the non-technological basis of the practice of heat treatment.

2. Heat treatment: the process and social significance

2.1. Heat treatment of lithic raw materials

Heat treatment of lithic raw materials is a lithic production technology which has been practised throughout the greater part of the human history (for a comprehensive review see Domanski & Webb 2007). Various ethnographic accounts from North America and Australia demonstrate that it was practiced until recently (*e.g.*, Flenniken & White 1983; Hester 1972). Heating siliceous rocks by controlled fire alters their physical properties and improves their flaking quality, thus facilitating the production of lithic tools, particularly when a pressure flaking technique, for both blade detachment and edge retouch, is involved (Delage & Sunseri 2004; Inizan & Tixier 2000; Mourre *et al.* 2010). Rocks can be heated in the form of a block, rough-out or core preform in order to facilitate the knapping (or pressure detachment) of blades and flakes and the subsequent shaping of tools. Alternatively, heat treatment can be applied to flakes or blades when it is only to facilitate the shaping of tools by edge retouch. In many cases, thermal treatment changes the colour and texture of rocks. Apart from a burnt-looking outer surface, distinctive change is seen on the surface flaked after heat treatment. Usually, colour changes towards pinkish hues, due to the iron compound being oxidised to haematite (Purdy & Brooks 1971; Schindler *et al.* 1982). Also, flaked surfaces often become glossier or greasily lustrous due to the microstructural change of heated rocks, which produces a smoother fracture surface that tends to reflect more light (Domanski & Webb 2007; Schmidt *et al.* 2012). This change can be a clue to identifying the evidence of heat treatment with the naked eye, although one must be careful that the degree of change in colour and increase in lustre relates to the type of rock as similar change can occasionally be produced by taphonomic causes, particularly in the case of dark rock when distinctive change is not clearly visible (Domanski & Webb 1992); surface lustre is more reliable for identification (*e.g.*, Rowney & White 1997; Schmidt 2013). Sometimes it is possible to determine when heat treatment was applied. For instance, if a retouched blade has a lustrous surface only on the retouched scars but not on the main flaked surface on the dorsal and

ventral faces, it means that the blade was knapped before heat treatment and was retouched after it.

2.2. Mechanical properties of heated rocks and optimal condition of heat treatment

The improvement in the flaking property of flint can be explained by microstructural change. Many studies have contributed to identifying thermal alteration of the mechanical property of rocks using various analytical methods.

There are still on-going debates on the mechanism of the physical alteration of heated rocks, but the consensus is that it is a microstructural change, induced by controlled heating, that allows fractures to propagate more readily and enhances its knapping quality. Domanski and Webb (1992) summarised the microstructural changes suggested by various researchers into three major hypotheses: silica fusion, microcracking and silica recrystallisation. In addition to these, the latest proposal by Schmidt *et al.* (2012) can be added as a further hypothesis, which explains that heating induces the formation of new Si-O-Si bridges that cause the increased hardness of rocks and reduce their fracture toughness. Conclusions are yet to be drawn, but it is likely that different mechanisms are responsible for the alteration in different types of rocks and that more than one of these changes occur simultaneously during heat treatment.

The optimal conditions that cause the microstructural change for successful heat treatment have been sought by experimental studies (*e.g.*, Crabtree & Butler 1964; Inizan *et al.* 1976; Purdy & Brooks 1971). Different studies often show different results because optimal conditions vary according to rock types, lithologies and sizes. Our general understanding is, however, that the optimal condition for flint is to heat it at a temperature between 200 °C and 450 °C for a duration of 30 minutes to 24 hours or longer. Heating at a lower temperature requires a longer heating time, while heating at too high a temperature or heating too rapidly often causes crazing or fracture due to thermal shock and makes the flint unusable. For instance, Griffiths *et al.* (1987) demonstrated that the heating of flint core preforms at 350 °C for 30 minutes, at 300 °C for 1 hour and at 250 °C for 24 hours all resulted in successful heat treatment. It has also been suggested that coarse lithologies require a higher temperature (Domanski & Webb 1992) and larger pieces need to be heated at a lower temperature for a longer period (Mercieca & Hiscock 2008). On the other hand, recent studies by Schmidt *et al.* (2015a) have demonstrated that while the transformation of the physical property of a certain type of flint is achieved in 1 hour of heating at a peak temperature higher than 200 °C, a slower heating rate is required to let water evacuate from the heated flint. Thus, the actual time needed for the heat treatment of flint with high water contents can be longer. It is also not unreasonable to assume that heating a large volume of rocks at lower temperatures takes longer to allow the heat to penetrate deep inside the rocks. Furthermore, in heat treatment using an open fire, the way flint is heated - for instance, whether the flint is buried in sand beneath the fire or just thrown into an ashy hearth covered with embers - must affect the actual time spent in the process of thermal alteration. In any case, all these studies, without doubt, show that successful heat treatment depends on the control of heating time and temperature.

2.3. Archaeological evidence and social significance of lithic heat treatment

Archaeological evidence of heat treatment is seen all over the world. Domanski and Webb (2007) have already provided a comprehensive review, and there is no need to repeat it here. Only two time periods and regions, the Palaeolithic and the Neolithic in the Near East and the Middle Stone Age in southern Africa, are mentioned here in order to support the following discussion.

In the Near East, heat treatment was not an uncommon technique at prehistoric sites. Palaeolithic evidence has been reported from the Mousterian site of the Ras-el-Kelb Cave (Lebanon), which dates back to ca.110,000 BP (Domanski & Webb 2007), and an Upper Palaeolithic level of Ksar Akil (Lebanon), ca. 35,000 cal. BP (Griffiths *et al.* 1987). While these two examples were only visually identified, the recent study using Fourier transform infrared spectroscopy for the Upper Palaeolithic flint industry at Manot Cave (Israel), ca. 40,000-31000 cal. BP (Weiner *et al.* 2015), has demonstrated that some flint debitage was probably heated during the process of heat treatment.

The evidence increases for the Late Epipalaeolithic and the Neolithic, as the use of heated flint has been reported from various Natufian and Pre-Pottery Neolithic sites (ca.15,000-9000 cal. BP), particularly in the south Levant (Delage & Sunseri 2004; Nadel 1989). At the Early Natufian site of Wadi Hammeh 27, heat treatment was applied to bladelet cores to facilitate bladelet production (Edwards & Edwards 1990). In southeast Anatolia and north Mesopotamia, heat-treated flint artefacts have been found at sites from the 10th to 9th millennia, which are roughly contemporary to Hasankeyf Höyük. For instance, Gusir Höyük, which is located about 30 km east of Hasankeyf Höyük, has produced a lithic assemblage that includes many heat-treated flint artefacts (Karul 2011: fig.14; personal communications with Altınbilek-Algül in March 2013). At Nemrik 9 about 170 km southeast of Hasankeyf Höyük, the excavator has reported that 40% of cores, blades and tools carry traces of contact with fire (Kozłowski & Szymczak 1992: 43), although it is not certain whether this represents deliberate heat treatment.

Given that visual identification of heated flint is sometimes not easy, it is likely that there would have been more sites where heat treatment was actually exercised. However, although heat treatment is a ubiquitous technique, it never became an overwhelming feature in lithic production in the Near East. Even in the later phase of the Neolithic, there are many sites which entirely lack evidence of heat treatment. When the evidence is detected, it is usually only seen in part of the flint assemblages and unheated flint is usually more dominant. The evidence from Hasankeyf Höyük fits this situation.

The archaeological significance of heat treatment has recently become an issue of active debate following the discovery of one of the earliest pieces of evidence of this technique in the Middle Stone Age sites in South Africa. Heat-treated silcrete tools from Pinnacle Point are estimated to date back to at least 71,000 BP and probably 164,000 BP (Brown *et al.* 2009). Other evidence from a similar period has been reported from Blombos Cave, ca. 75,000 (Mourre *et al.* 2010), and the Howiesons Poort level of Diepkloof Rock Shelter, ca. 65,000-60,000 BP (Schmidt *et al.* 2015b). Arguing that heat treatment was a technique conducted by early modern humans, these studies have often approached the issue of early heat treatment from an evolutionary viewpoint. For example, it has been argued that heat treatment was an advanced, complex technological innovation which enabled early modern humans to produce sharper and more efficient tools and offered them behavioural advantages (Brown *et al.* 2009). It is indeed not unusual that the studies of heat treatment emphasise technological advancement based on its functional advantage in the production and use of stone tools. The fact that the study of heat treatment first developed in North American archaeology in the 1970s may be related to the popularity of evolutionary thought in the study of lithic heat treatment. It is, in any case, not surprising that the functional view is dominant for heat treatment in Palaeolithic South Africa, where the behavioural evolution of modern humans forms a central part of research interest.

Indeed, a utilitarian account of heat treatment from an evolutionary perspective should be appropriate for the case of the Palaeolithic study. However, when considering the case of the Neolithic site of Hasankeyf Höyük, heat treatment cannot simply be explained from a utilitarian viewpoint. We can observe that heat treatment at Hasankeyf Höyük was conducted

in a rather inefficient, opportunistic manner that was not motivated by a technical necessity for producing effective tools. In different contexts, the role and meaning of heat treatment must be different.

3. Flint heat treatment at Hasankeyf Höyük

Hasankeyf Höyük is a sedentary hunter-gatherer settlement located in the upper Tigris valley in southeast Turkey (Figure 1). The botanical and faunal evidence show no sign of the domestication of plants and animals, while many subterranean round buildings with solid stone walls, repeatedly built throughout a very thick cultural deposit, suggest that the site was a sedentary village occupied year round (Miyake *et al.* 2012; Maeda 2018).

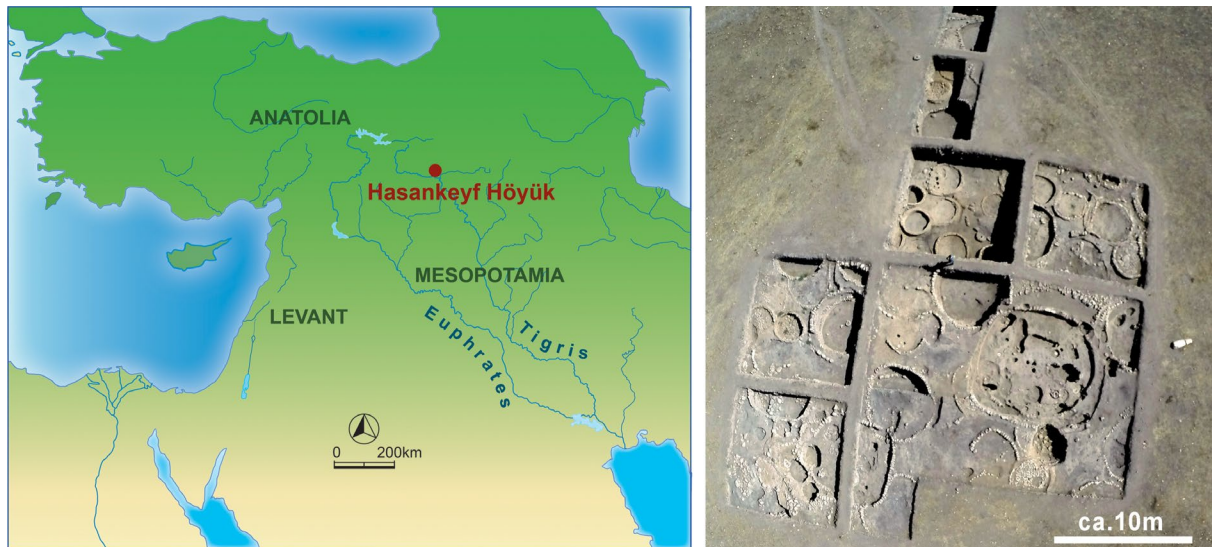


Figure 1. Location of Hasankeyf Höyük and an aerial view of the excavated buildings.

The lithic industry is characterised by microliths (scalene triangles and those with a symmetrical foliate shape) and other formal tools usually made on blade and bladelet blanks which were produced from single-platform cores by direct percussion (Maeda 2018). For the raw materials of these artefacts, flint of good quality and size is locally available in the form of river cobbles scattered around the site or in the form of nodules embedded in the limestone bedrock a few kilometres away (Figure 2). Both types of flint were used in the same way for the production of blades, bladelets and flakes and for the manufacture of all types of tools. Traces of heat treatment are observed in about 10% of all the flint artefacts (ca. 5000 pieces) recovered from the later phase of the occupation. The ratio increases to about 20% among the blade and bladelets. Although no petrographic or geochemical analysis has yet been conducted, the pinkish hue and well-developed greasy lustre on the flaked surface are very distinctive when compared to the unheated flint artefacts (Figure 3). Although some flint artefacts which were heat treated but did not develop visual change, for instance due to a too low heating temperature, cannot be visually identified, the visual change of heated flint at Hasankeyf Höyük is so distinctive that it can be a criterion for identifying thermal alteration. Experiments using the same types of local flint, as discussed below, have confirmed the reliability of this visual distinction.



Figure 2. Local flint available near Hasankeyf Höyük. Left: River cobbles found on the river terrace of the Tigris. Right: Flint nodules embedded in a limestone bedrock at the foothill of Raman Dağ.



Figure 3. Flint artefacts recovered from Hasankeyf Höyük. 1-3: Heat-treated flint. 4, 5: Close-up view of the flaked surface after heat treatment. 6, 7: Unheated flint (1: Overshoot blade; 2, 6: Core; 3, 7: Blades).

Heat-treated artefacts include not only blades and tools but also cores and flakes. Various local flints, including both river cobbles and nodules, were subjected to heat treatment. When observed, the pinkish lustrous surface is always seen on both dorsal and ventral faces of blades and flakes as well as on retouched scars. This means that these blades and flakes were knapped after heat treatment and suggest that the flint was heated before core reduction began, probably at a core preform stage.

The blades and bladelets produced from heated flint were usually shaped into arrowheads and scrapers (Figure 4), which are the most common and standardised tools, although no essential necessity to use heated flint for the manufacture of these tools can be assumed. It must be noted that although the heat treatment must have improved the flaking quality of the local flint and made it possible to produce larger blades, the quality of the local flint was good enough to produce regular blades even in the absence of heat treatment. The same type of blades, bladelets and tools could be produced using unheated flint so that blade production using heated flint did not have much functional advantage over unheated flint. This is confirmed both by the absence of blade production using a pressure technique and the lack of evidence for tool manufacture using invasive pressure flaking retouch at Hasankeyf Höyük, both of which require raw materials of very high quality and is often facilitated by heat treatment (Inizan & Tixier 2000). In fact, the same type of blades and tools were already in production before the heat treatment was introduced in the later phase of the occupation (Figure 3: 7).



Figure 4. End scrapers and arrowheads (Nemrik type) made of heat-treated flint.

In addition, the tools made with heated flint at this site do not necessarily have functional advantages over those made with unheated flint. For instance, no difference is observed in the sharpness of the working edges between tools made on heated and unheated flints. Actually, the fact that many scrapers were made of heated flint does not really support the assumption that heat treatment was used to improve the edge sharpness, because rather robust working edges instead of sharp ones are needed for scrapers. It is known that heat treatment enables one to make sharper working edges, but it also makes the working edges more vulnerable to use-wear (Olausson 1983).

Apparently, the heat treatment practiced at Hasankeyf Höyük was a dispensable technique which was not necessarily needed to meet utilitarian demand. Elsewhere, the decline of a simple correlation between the effect of heat treatment and functional and utilitarian advantage has been proposed by other researchers (Delage & Sunseri 2004, Wadley & Prinsloo 2014). This suggests that the reason why heat treatment was practiced at

Hasankeyf Höyük must be multifaceted and involve, to a large extent, social and cultural preferences.

What is more intriguing is that this assemblage includes many flint artefacts which were apparently overheated, or nearly overheated. There are many flint fragments that were fractured by thermal shock, often having angular or pod-lid fractures that are typical of fracture caused by thermal damage (for the latest arguments on the physical mechanism of thermal damage, see Schmidt 2014). In addition, there are many flint blades and flakes which have a very reddish colouration, very well-developed lustre and sometimes burnt-looking cortex. It is known from the experimental heating that these features are more clearly visible on the sample heated at higher temperatures, including those which were fractured due to thermal breakage. It is difficult to quantify the amount of these thermally fractured pieces because when flint fractures by overheating it often shatters into hundreds of small pieces so that a simple count of shattered pieces does not really represent the number of pieces of flint which resulted in fracture from overheating. It can only be said that there are as many overheated shattered flint fragments as successfully heated flint artefacts.

It is unlikely that these overheated flint fragments were the products of accidental firing. Indeed, it is not unusual to have accidentally fired flint artefacts in lithic assemblages from Neolithic settlements in the Near East. In fact, the presence of some burnt blades and flakes from Hasankeyf Höyük suggests that they were probably accidentally burnt. However, the amount of overheated flint fragments recovered from the later phase of this site, where heat treatment was practiced, is much higher than that in the earlier phase, where the evidence of heat treatment is absent. Also, the overheated pieces are mostly chunky fragments and only a few blades and tools are present. This suggests that most of these overheated fragments derived from intentional heat treatment rather than accidental firing. The fact that animal bones recovered from the same contexts showed hardly any signs of burning may also suggest that accidental firing of artefacts did not occur to the extent which would have produced such a large number of overheated flint fragments.

Therefore, it is more likely that these overheated flint fragments were produced by intentional heating which failed to achieve successful heat treatment. It might be possible to assume that shattering of flint by thermal shock was conducted on purpose, particularly in the Palaeolithic, because the edges of the shattered fragments can be sharp and usable as working edges of tools. However, it is unlikely to be the case for Hasankeyf Höyük in the Neolithic period, where regular blades with sharp edges were constantly produced using unheated flint. The presence of many overheated flints at Hasankeyf Höyük, therefore, suggests that heat treatment practiced at this site frequently ended in failure.

Now, the question is why the practice of heat treatment at Hasankeyf Höyük failed so often. Is it because successful heat treatment requires a high level of technological skill which is really difficult to master? To answer this question, experimental studies using the local flint procured around Hasankeyf Höyük were necessary.

4. Experiments with local flint

4.1. Experiments using an electrical furnace

To understand how difficult it is to achieve successful heat treatment, the optimal heating conditions for the local flint at Hasankeyf Höyük must be first identified. For this purpose, experiments using an electrical furnace were carried out. Since different types of flint behave differently when heated, it is necessary to test the local flint. Twelve samples of two types of flint procured in the form of river cobbles and nodules were used (Figure 5). The river cobbles were collected near the site on the river terrace of the Tigris. They have a light grey to light brown colour, often with small white fossil inclusions and a thin yellow cortex. The

nodules were obtained from the flint seams in the limestone bedrock at the foothill of Raman Dağ about 2.5 km north of the site along the wadi Sinniboğaz Deresi. They have a brownish-grey tinge with blueish-grey spots of fossil inclusions. The samples were roughly shaped into irregular core preforms 5-10 cm in maximum dimension and placed in a sand bath within a glass container. Then, the containers were placed in a heating chamber of an electrical furnace with free access to oxygen and heated at different temperatures (250, 350, 400 and 450 °C) for different periods (15 minutes, 1 hour, 5 hours and 10 hours). Different heating speeds were also tested. More detail description of the samples and the experimental conditions have been published elsewhere (Maeda 2017).

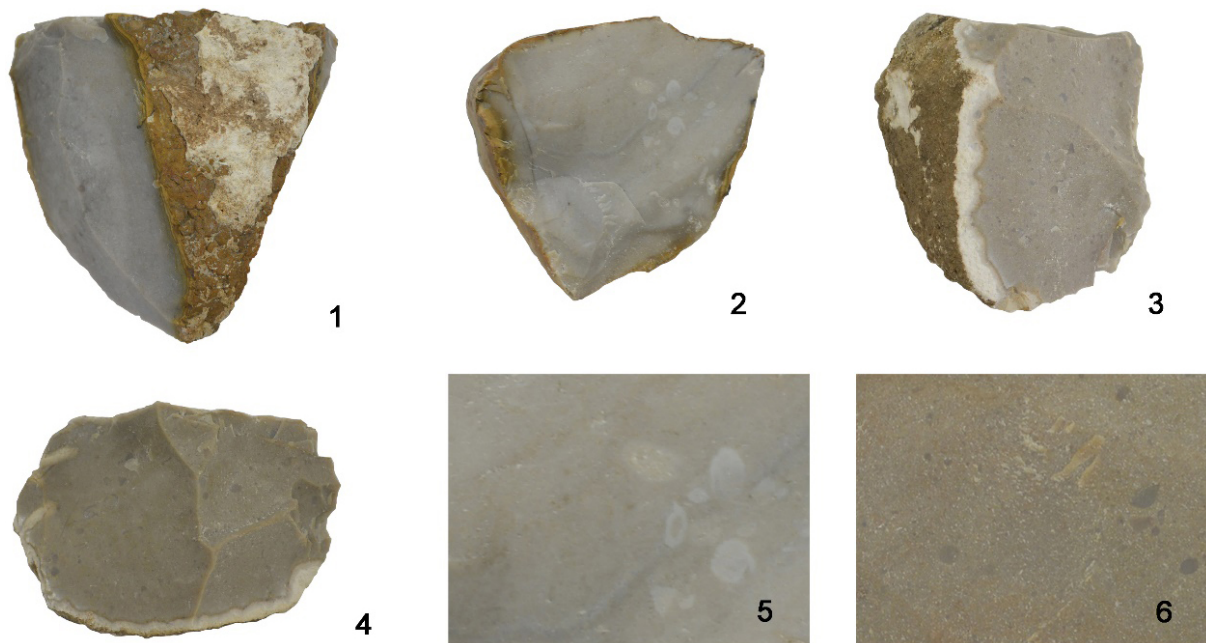


Figure 5. Flint preforms used for experiments conducted with an electrical furnace. 1, 2: Made of river cobble flint. 3, 4: Made of nodule flint. 5: Close-up view of river cobble flint. 6: Close-up view of nodule flint.

The results are as follows. When the samples were heated up to 250 °C taking 90 minutes (at the rate of ca. 3 °C/min.), 1 hour heating at the peak temperature was not long enough and no change was observed in the flints, while 5 and 10 hours heating at this temperature were both successful. When heated up to 350 °C and 400 °C at the same heating rate, heating for 1 hour or longer at the peak temperature resulted in success (Figure 6). Heating for a more extended period (5 and 10 hours) did not cause any overheating damage (see Schmidt *et al.* 2015a, which suggests that continuous heating after 1 hour only produces a very small supplementary effect). Heating up to 350 °C at a faster heating rate, taking only 30 min (10 °C/min.), which is much faster than the heating rate (0.1-1.0 °C/min.) proposed by Schmidt (2014) for French Turonian flint, and then holding it at this peak temperature for 1 hour, was equally successful, but holding it only for 15 minutes was too short to make any change in the flint sample. On the other hand, all three samples heated up to 450 °C developed thermal breakage and became unusable for knapping regardless of heating time and speed (Figure 7): the first one was heated to 450 °C in 30 minutes (14 °C/min.) and held at this temperature for 15 minutes, the second one was heated to 450 °C in 2 h (3.5 °C/min.) and held for 1 hour, and the last sample reached 450 °C in 3 hours (2.4 °C/min.) and held for 1 hour.

In summary, these results demonstrate that the local flint at Hasankeyf Höyük must be heated below 450 °C for successful heat treatment, and that if heated at 250 °C a longer heating time is required. At 300-400 °C, 1 hour heating is good enough even at a faster heating rate (10 °C/min.), and heating for many hours does not cause overheating failure. It is,

therefore, assumed that as far as one can control the maximum temperature, heat treatment of this local flint is not a particularly difficult task.



Figure 6. Flint samples successfully heat treated at 350 °C. 1, 4: Blades flaked before heat treatment. 2, 5: Blades flaked after heat treatment. 3: Heat-treated core (1-3: River cobble flint; 4, 5: Nodule flint).



Figure 7. Flint samples broken by overheating thermal damage at 450 °C.

4.2. Experiments using open fire

To confirm this assumption, further experiments using an open fire in a context more closely matching the conditions in the Neolithic were carried out. They were conducted near the site of Hasankeyf Höyük during a field season on sunny, and not windy, days in August 2014. The method of heating is quite simple when compared to that known from ethnographic accounts (Hester 1972) and experimental studies by other researchers (*e.g.*, Brown *et al.* 2009; Mercieca & Hiscock 2008). The heating process described below was carried out twice, and in total, 13 samples of core preforms were tested. The samples were made of the same type of local flint as those used for the experiments with an electrical furnace and roughly shaped to the size of 5-10 cm in length and 3-5 cm in thickness. A thermocouple probe (Type K) was used to measure the temperature.

First, a shallow pit about 10 cm deep was dug into very dry ground and partly encircled with a single course of stones. Then, a fair amount of firewood was burnt within the pit for a

couple of hours until it was all burnt down to embers and ashes, which formed a 5-cm-thick layer. After letting the embers and ashes cool down for a while, the flint samples were thrown into the pit and directly covered with the ashes and embers, which were still slightly glowing inside (Figure 8). The samples were heated between 200 °C and 500 °C for 5 h. During the 5 h heating, the embers were poked three times and extra firewood was added once in order to maintain the temperature and the amount of embers covering the flint samples. After 5 hours of heating, the samples were left in the pit for 3 hours to cool down before they were finally removed.

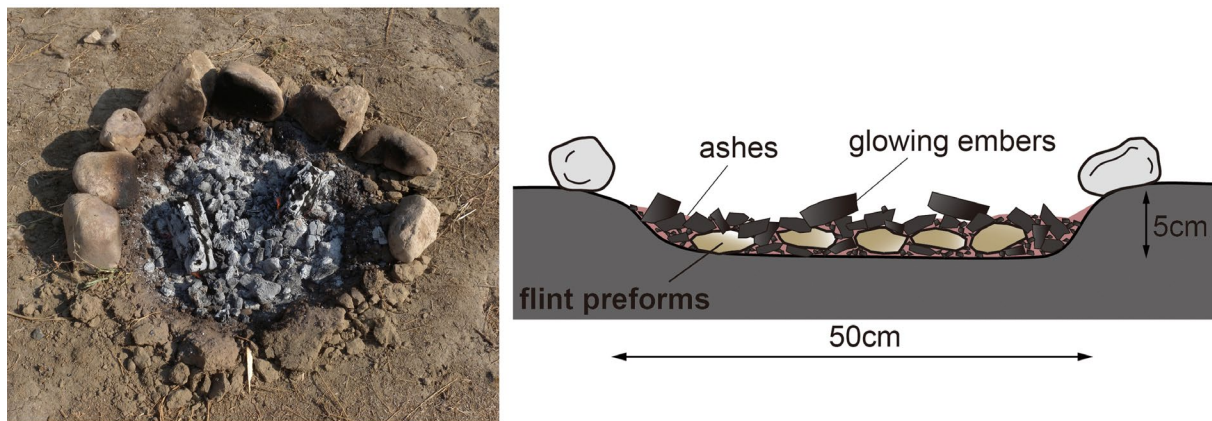


Figure 8. Heat treatment using open fire. Left: The samples are covered with embers. Right: Schematic diagram of the heating pit.

The results were quite successful. The flaking property of the successfully heated preforms improved very well. When knapped by direct percussion, many were flaked more easily and with less knapping force than before heating. The improvement was immediately recognisable as they were knapped. On the flaked surface, a distinctive change in colour towards a pinkish hue and greasy lustre was observed (Figure 9). Figure 10 shows a comparison of the experimental samples and the archaeological artefacts excavated from Hasankeyf Höyük. They look almost identical in their colour and lustre. It is thus highly probable that heat treatment at Hasankeyf Höyük was conducted in a similar way using the same types of local flint. On the other hand, in this experiment, four samples were crazed or cracked by thermal shock. This was probably because the temperature sometimes increased beyond 450 °C in particular parts of the pit, especially after extra firewood was added. The overall success rate was about 70%.

5. Discussion

5.1. Heat treatment as an easy technological process

Given the results of these experiments, it can be argued that the successful heat treatment of the local flint at Hasankeyf Höyük can be achieved without advanced technology or particular investment. It certainly requires appropriate knowledge and some experience concerning the optimal temperature and duration of heating time. However, once a suitable method of heating has been discovered, it requires neither particularly high technical skill nor complex heating facilities. The timing at which flint preforms are thrown into the glowing embers is important, since if the embers are too hot, the heating temperature easily exceeds 450 °C and causes thermal damage. Nevertheless, when thermal fracture by overheating occurs, it can easily be recognised by its cracking sound even when the flint preforms are buried beneath the embers. This usually happens within a few minutes after the preforms are thrown into the embers, and thus, one can immediately learn that the timing of throw-in was

too soon and the temperature was still too high. If overheating fracture happened to the flint preform first thrown in, then the second preform can be thrown in after a while when the temperature has lowered. After all the flint preforms have been thrown in and covered with embers at the appropriate temperature, one needs to only pay attention to maintaining the maximum temperature below 450 °C. The minimum temperature needs to be higher than 250 °C, but this is not as critical as the maximum temperature because a lower temperature does not cause any damage to the flint. One can only raise the heating temperature by poking embers or adding firewood when one realises the temperature is too low. While heating longer hours secures successful heat treatment, one does not need to sit down by the heating pit to keep an eye on it all the time. Taking care of the heating conditions every 30 minutes to an hour would be enough to maintain the right temperature. In the experiment, a thermocouple probe was used to examine the temperature of the heating environment. However, the temperature can be easily managed without modern equipment once an individual has acquired relevant knowledge through trial and error.



Figure 9. Flint core preform successfully heat treated by open fire. Left: Before heat treatment. Right: After heat treatment (a couple of blades were flaked after heat treatment, and the flaked scars show a greasy lustre).



Figure 10. Comparison between the experimentally heat-treated samples and the archaeological artefacts. 1, 3: Experimental flakes flaked after heat treatment. 2, 4: Archaeological flakes recovered from Hasankeyf Höyük.

It has been suggested that while the heat treatment of silcrete is relatively easy, that of flint is complicated and sophisticated technology (*e.g.*, Schmidt *et al.* 2013). The complicated mechanism of flint heat treatment has been well investigated for the case of Turonian flint in France, which has a high water content (Schmidt 2014). However, it does not seem to be the case for the local flint at Hasankeyf Höyük. Indeed, it may be a difficult process if one tries to achieve a 100% success rate every time. However, if it does not need to be perfect and if failure is allowed to some extent, it is a relatively easy technological process. It would have been equally easy to improve the success rate as more knowledge and experience were accumulated.

5.2. Deliberate choice of an inefficient technology

It is thus concluded that successful heat treatment was a technologically easy process and could have been achieved with a high success rate by the people of Hasankeyf Höyük. However, this does not seem to be what happened at this site, because many overheated pieces included in the flint assemblage suggest frequent failure in heat treatment. This means that the frequent failure was not caused by the people's inability to conduct successful heat treatment but resulted from their attitude that the improvement in success rate was not a primary concern. It is likely that heat treatment was conducted in an expedient and opportunistic way, where it frequently ended in failure as much as it ended in success. The people preferred to practice heat treatment in a more relaxed manner and did not hesitate to make frequent failures. This would be particularly so when plenty of local flint was at hand in the vicinity of the site and firewood was also easily available from the forest once covering Raman Dağ.

Pierre Lemonnier once argued the idea of technological choice, in which technology is considered a type of social production that is determined by various non-technological social phenomena. Societies often arbitrarily adopt certain technologies and reject others even when the technology they adopt is technologically equal to or even less efficient than the others (Lemonnier 1992). Lemonnier gave the example of a modern commercial airplane. Aircraft which are technologically advanced but have odd-looking unusual silhouettes are sometimes not successfully adopted in the airplane industry, because for most engineers, they are not what aircrafts should look like and because they require new piloting techniques which are not welcomed by most pilots, who prefer the traditional routine operation of the aircraft. Here, the choice is made not according to technological efficiency but according to cultural tradition or social preference.

In a similar line of reasoning, the argument made by the theory of Social Construction of Technology (Pinch & Bijker 1987) helps us understand the character of heat treatment technology at Hasankeyf Höyük. Pinch and Bijker argued that technological problems can often be solved in a non-technological way. This is because the decision as to whether a technological problem has been solved is often made by the members of societies who often make a decision on a non-technological basis. Drawing on the example of early bicycles with a large front wheel, Pinch and Bijker argued that the problem of lack of safety with this type of high-wheel bicycle was sought to be solved not by improving its technology but by advertising that the bicycles were perfectly safe, in order to persuade people to think that the technological problem had been solved. This way, it is possible to assume that technological inefficiency in heat treatment at Hasankeyf Höyük was not something that needed to be overcome but something positively accepted by people.

It is more likely that what looks like a failure in the practice of heat treatment at Hasankeyf Höyük was not necessarily a technological deficiency for the people at this site but was a deliberate choice by them of an inefficient, opportunistic technology. As experimental

studies show, heat treatment certainly improves the flaking quality of local flint and it must have been a pleasure for flint knappers to knap good-quality flint. This may be the reason why heat treatment was practiced at Hasankeyf Höyük. But it is in any case certain that flint heat treatment at this site was related to neither the efficiency of lithic production nor to the effectiveness of lithic tools.

6. Conclusions

The results of the experimental studies in comparison with the archaeological evidence have demonstrated how heat treatment was practiced at Hasankeyf Höyük. Although the heat treatment of local flint was not a difficult technological process, people at this site preferred to carry out the process in an opportunistic way and did not try to improve its efficiency. This indicates that the use of lithic technology in past societies was not always motivated by a desire for greater technological efficiency. We tend to think that technology is related to the improvement in efficiency and regard failure as negative. However, this was not always the case in the past. At Hasankeyf Höyük, the inefficient practice of heat treatment was people's deliberate choice and the failure was just a part of their routine lithic production. It is difficult to identify any particular social elements behind this deliberate choice. However, studying lithic technology from this perspective gives us a critical insight into the study of ancient lithic technology.

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References

- Beauchamp, E.K., & Purdy, B.A. 1986, Decrease in fracture toughness of chert by heat treatment. *Journal of Materials Science*, 21: 1963-1966. doi:10.1007/BF00547934
- Bleed, P., & Meier, M. 1980, An objective test of the effects of heat treatment of flakeable stone. *American Antiquity*, 45: 502. doi:10.2307/279865
- Brown, K.S., Marean, C.W., Herries, A.I.R., Jacobs, Z., Tribolo, C., Braun, B., Roberts, D.L., Meyer, M.C., & Bernatchez, J. 2009, Fire as an engineering tool of early modern humans. *Science*, 325: 859-862. doi:10.1126/science.1175441
- Crabtree, D.E., & Butler, B.R. 1964, Notes on experiments in flint knapping: 1. Heat treatment of silica materials. *Tebawa*, 7: 1-6.
- Delage, C., & Sunseri, J. 2004, Lithic heat treatment in the Late Epipalaeolithic of southern Levant: Critical review of the evidence. *Lithic Technology*, 29: 161-173. doi:10.1080/01977261.2004.11721018
- Domanski, M., & Webb, J.A. 1992, Effect of heat treatment on siliceous rocks used in prehistoric lithic technology. *Journal of Archaeological Science*, 19: 601-614. doi:10.1016/0305-4403(92)90031-W
- Domanski, M., & Webb, J. 2007, A review of heat treatment research. *Lithic Technology*, 32: 153-194. doi:10.1080/01977261.2007.11721052

- Domanski, M., Webb, J.A., & Boland, J. 1994, Mechanical properties of stone artefact materials and the effect of heat treatment. *Archaeometry*, 36: 177-177.
doi:10.1111/j.1475-4754.1994.tb00963.x
- Edwards, P.C., Edwards, W.I. 1990, Heat Treatment of Chert in the Natufian Period. *Mediterranean Archaeology*, 3: 1-5. URL: <http://www.jstor.org/stable/24666567>
- Flenniken, J.J., & Garrison, E.G. 1975, Thermally altered novaculite and stone tool manufacturing techniques. *Journal of Field Archaeology*, 2(1-2): 125-131.
doi:10.2307/529623
- Flenniken, J.J., & White, J.P. 1983, Heat treatment of siliceous rocks and its implications for Australian prehistory. *Australian Aboriginal Studies*, 1983(1): 43-48.
- Griffiths, D.R., Bergman, C.A., Clayton, C.J., Ohnuma, K., Robins, G.V., & Seeley, N.J. 1987, Experimental investigation of the heat treatment of flint. In: *The Human Uses of Flint and Chert: Proceedings of the Fourth International Flint Symposium, Held at Brighton Polytechnic, 10-15 April 1983* (Sieveking, G. de G., & Newcomer, M.H., Eds.), Cambridge University Press, Cambridge and New York: p. 43-52.
- Hester, T.R. 1972, Ethnographic evidence for the thermal alteration of siliceous stone. *Tebiwa*, 15: 63-65.
- Inizan, M.-L., Roche, H., & Tixier, J. 1976, Avantages d' un traitement thermique pour la taille des roches siliceuses. *Quaternaria*, 19: 1-18.
- Inizan, M.-L., & Tixier, J. 2000, L'émergence des arts du feu: le traitement thermique des roches siliceuses. *Paléorient*, 26(2): 23-36. doi:10.3406/paleo.2000.4707
- Karul, N. 2011. Gusir Höyük. In: *The Neolithic in Turkey. New Excavations and New Research. The Tigris Basin* (Özdoğan, M., Başgelen, N., & Kuniholm, P., Eds.), Archaeology & Art Publications, Istanbul: p.1-17.
- Kozłowski, S.K., & Szymczak, K. 1992, Flint industry. In: *Nemrik 9. Pre-pottery Neolithic site in Iraq, Vol. 2: House No 1/1 A/1 B*. (Kozłowski, S.K., Ed.), Warsaw University Press, Warsaw: p. 43-79.
- Lemonnier, P. 1992, *Elements for an Anthropology of Technology*. Museum of Anthropology, University of Michigan, Ann Arbor, 129 p.
- Maeda, O. 2018, Lithic analysis and the transition to the Neolithic in the upper Tigris Valley: recent excavations at Hasankeyf Höyük. *Antiquity*, 93(361): 56-73.
doi:10.15184/aqy.2017.219
- Maeda O. 2017, Experimental implications for flint heat treatment at Hasankeyf Höyük. In: *The exploitation of Raw Materials in Prehistory: Sourcing, Processing and Distribution* (Pereira T., Terradas X., & Bicho, N., Eds.), Cambridge Scholars Publishing, Newcastle upon Tyne: p. 601-612.
- Mandeville, M.D. 1973, A consideration of the thermal pretreatment of chert. *Plains Anthropologist*, 18: 177-202.
- Mercieca, A., & Hiscock, P. 2008, Experimental insights into alternative strategies of lithic heat treatment. *Journal of Archaeological Science*, 35: 2634-2639.
doi:10.1016/j.jas.2008.04.021

- Miyake, Y., Maeda, O., Tanno, K., Hongo, H., & Gündem, C.Y. 2012, New excavations at Hasankeyf Höyük: a 10th millennium cal. BC site on the Upper Tigris, southeast Anatolia. *Neo-Lithics*, 1(12): 3-7.
- Mourre, V., Villa, P., & Henshilwood, C.S. 2010, Early use of pressure flaking on lithic artifacts at Blombos Cave, South Africa. *Science*, 330: 659-662. doi:10.1126/science.1193769
- Nadel, D. 1989, Flint heat treatment at the beginning of the Neolithic period in the Levant. *Journal of the Israel Prehistoric Society*, 22: 61-67.
- Olausson, D.S. 1983, Experiments to investigate the effects of heat treatment on use-wear on flint tools. *Proceedings of the Prehistoric Society*, 49: 1-13. doi:10.1017/S0079497X00007933
- Pinch, T.J. & Bijker, W.E. 1987, The Social construction of facts and artifacts: Or how the sociology of science and the sociology of technology might benefit each other. In: *The Social Construction of Technological Systems* (Bijker, W.E., Hughes, T.P., & Pinch, T.J., Eds.), MIT Press, Cambridge, MA: p. 17-50.
- Purdy, B.A., & Brooks, H.K. 1971, Thermal alteration of silica minerals: an archeological approach. *Science*, 173: 322-325. doi:10.1126/science.173.3994.322
- Robins, G.V., Seeley, N.J., McNeil, D.A.C., & Symons, M.C.R. 1978, Identification of ancient heat treatment in flint artefacts by ESR spectroscopy. *Nature*, 276: 703-704. doi:10.1038/276703a0
- Rowney, M., & White, J.P. 1997, Detecting heat treatment on silcrete: experiments with methods. *Journal of Archaeological Science*, 24: 649-657 doi:10.1006/jasc.1996.0147
- Schindler, D.L., Hatch, J.W., Hay, C.A., & Bradt, R.C. 1982, Aboriginal thermal alteration of a central Pennsylvania jasper: analytical and behavioral implications. *American Antiquity*, 47: 526-544. doi:10.2307/280233
- Schmidt, P. 2014, What causes failure (overheating) during lithic heat treatment? *Archaeological and Anthropological Sciences*, 6: 107-112. doi:10.1007/s12520-013-0162-3
- Schmidt, P., Léa, V., Sciau, P., & Fröhlich, F. 2013, Detecting and quantifying heat treatment of flint and other silica rocks: a new non-destructive method applied to heat-treated flint from the Neolithic Chassey culture, southern France: heat treatment of flint from the Chassey culture, southern France. *Archaeometry*, 55: 794-805. doi:10.1111/j.1475-4754.2012.00712.x
- Schmidt, P., Masse, S., Laurent, G., Slodczyk, A., Le Bourhis, E., Perrenoud, C., Livage, J., & Fröhlich, F. 2012, Crystallographic and structural transformations of sedimentary chalcedony in flint upon heat treatment. *Journal of Archaeological Science*, 39: 135-144. doi:10.1016/j.jas.2011.09.012
- Schmidt, P., Paris, C., & Bellot-Gurlet, L. 2015a, The investment in time needed for heat treatment of flint and chert. *Archaeological and Anthropological Sciences*, (2015). doi:10.1007/s12520-015-0259-y
- Schmidt, P., Porraz, G., Bellot-Gurlet, L., February, E., Ligouis, B., Paris, C., Texier, P.-J., Parkington, J.E., Miller, C.E., Nickel, K.G., & Conard, N.J. 2015b, A previously undescribed organic residue sheds light on heat treatment in the Middle Stone Age. *Journal of Human Evolution*, 85: 22-34. doi:10.1016/j.jhevol.2015.05.001

- Wadley, L., & Prinsloo, L.C. 2014, Experimental heat treatment of silcrete implies analogical reasoning in the Middle Stone Age. *Journal of Human Evolution*, 70: 49-60. doi:10.1016/j.jhevol.2013.11.003
- Weiner, S., Brumfeld, V., Marder, O., & Barzilai, O. 2015, Heating of flint debitage from Upper Palaeolithic contexts at Manot Cave, Israel: changes in atomic organization due to heating using infrared spectroscopy. *Journal of Archaeological Science*, 54: 45-53. doi:10.1016/j.jas.2014.11.023
- Weymouth, J.W., & Mandeville, M. 1975, An X-ray diffraction study of heat-treated chert and its archaeological implications. *Archaeometry*, 17: 61-67. doi:10.1111/j.1475-4754.1975.tb00115.x