Journal of Archaeological Science 35 (2008) 2634–2639

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Experimental insights into alternative strategies of lithic heat treatment

Alison Mercieca[a], Peter Hiscock[b,*]

[a] National Museum of Australia, Canberra, Australia
[b] School of Archaeology and Anthropology, Australian National University, Canberra, ACT 0200, Australia

ARTICLE INFO

Article history:
Received 28 January 2008
Received in revised form 10 April 2008
Accepted 11 April 2008

Keywords:
Experiments
Heat treatment
Thermal fracture
Lithics
Palaeolithic

ABSTRACT

Conditions in which thermal fractures occur are explored experimentally, and the results are used to assess heat treatment strategies. We conclude that no single ‘critical temperature’ for thermal fracturing or heat treatment can be specified for any particular raw material, as has so often been attempted, because threshold temperatures exist in relationship to specimen sizes. Our experiments show that smaller specimens are resilient to greater ranges of temperature fluctuations than larger ones, and that by manufacturing/selecting specimens of smaller sizes there is more potential to heat them rapidly and to higher temperatures without producing thermal fractures. We hypothesize a continuum of heat treating strategies between a ‘slow and steady’ strategy, which has overwhelmingly dominated past experimental designs, and a ‘fast’ strategy, which has received much less attention. The paper discusses the economic and technological contexts to which different heat treating strategies might be suited.

1. Introduction

The process of heating siliceous rocks to improve their flakability, called *heat treatment*, is now recognized as a strategy widely used by prehistoric knappers, and experimental studies have been instrumental in building an understanding of how the process was carried out. By experimentally defining conditions in which favourable changes in raw material occurred, archaeologists sought to describe the process by which archaeological specimens were heat treated. However, a key requirement of successful heat treatment is that undesirable heat-induced cracks or fractures are not created. Surprisingly the conditions in which those ‘failures’ are produced have rarely been experimentally defined or used to help understand the limits of suitable heat treatment conditions (although see Purdy, 1974, 1975; Patterson, 1995; Mercieca, 2000). In this paper we present new evidence about the situations in which thermal damage is produced, and employ that information to evaluate existing claims of how heat treatment may have been undertaken in the past.

Our central concern is to evaluate the idea that heat treatment can only be accomplished through a laborious and lengthy process. In characterizing conditions for successfully heat treating rocks, many researchers have consistently advocated a process of slow and steady heating to an optimal maximum temperature, with a slow and steady cool down period. The common argument for this gradual and prolonged method is that heating material too rapidly or above the optimum temperature radically increases the risk of inducing fractures. This prevailing model has been challenged by a few researchers who have shown that heat treating may also have been achieved simply and rapidly (Griffiths et al., 1987). The circumstances in which such different approaches may have been employed have not hitherto been explored, mainly because previous experiments have not adequately tested the role played by other variables, particularly size, on the incidence of thermal stress. Specimen size has often been acknowledged as an important factor in avoiding thermal damage, but for the first time we present quantified information of the relationship between size and the ‘optimal temperatures’ for heat treatment, allowing a new evaluation of existing models of heat treatment strategies.

To this end we embarked on a suite of laboratory based experiments constructed to assess the conditions in which thermal stress, which would prevent successful heat treating, might occur. Our experimental design paid particular attention to the interactions between raw material type, size of specimens, rate of heating and cooling, and peak temperatures, allowing us to make quantitative statements about the nature of optimal conditions for heat treating. These data allow us to clarify the diversity of processes by which heat treating can take place and speculate on the economic and technological context in which alternative strategies might be adopted.

2. Framing experimental investigations into the process of heat treatment

Researchers have used experiments to develop macroscopic and microscopic methods to detect heat treated material in the

---

* Corresponding author.
E-mail addresses: a.mercieca@nma.gov.au (A. Mercieca), peter.hiscock@anu.edu.au (P. Hiscock).

0305-4403/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jas.2008.04.021

archaeological record (e.g. Robins et al., 1978; Pavlish and Sheppard, 1983; Olausson and Larsson, 1982; Rowney and White, 1997; Purdy and Brooks, 1971), to investigate microstructural alterations and mechanical changes that underlie the improved flakability that accompanies heat treatment (e.g. Crabtree and Butler, 1964; Purdy, 1974; Domanski and Webb, 1992), and to define optimum conditions for heat treating (e.g. Crabtree and Butler, 1964; Mandeville, 1973; Purdy, 1975; Price et al., 1982; Ahler, 1983; Joyce, 1985). It is the last field of enquiry that is the focus of this paper.

The pioneering paper on the subject appeared in 1964, when Crabtree and Butler demonstrated a method for successfully heat treating siliceous rocks, finally resolving doubts as to whether ancient knappers could have improved their raw materials with heat (see Crabtree and Butler, 1964, p. 1; Mandeville, 1973, p. 177; Rick and Chappell, 1983, p. 69). Crabtree and Butler (1964, p. 2) attributed their success to a number of factors, particularly their ability to control the length of time that specimens were heated and the temperature they reached, concluding that "For each type of silica mineral there appeared to be a critical temperature range below which, regardless of the length of time involved, no change would taken [sic] place and above which it would crack or craze". They additionally concluded that the rate of heating and cooling was important for success, claiming that "Any sudden raising or lowering of temperature, such as heating up the material too quickly or opening the oven door before slowly cooling off the oven, usually ended in extensive crazing of the mineral specimens". These statements about practices that could avoid thermal damage and heat treat rocks were extraordinarily influential; they inspired and shaped experimental investigations throughout the 1970s as researchers attempted to identify the ideal heating conditions for a variety of raw materials (e.g. Purdy and Brooks, 1971; Mandeville, 1973; Purdy, 1974; Flenniken and Garrison, 1975). Those experiments reinforced and expanded Crabtree's vision, reiterating the idea that material needed to be protected from high temperatures and too rapid a temperature change if thermal damage was to be avoided. This concept of gradual heating influenced the following generation of researchers who repeated the proposition that specimens must have been heat treated in a slow and steady fashion to avoid thermal fracture (e.g. Olausson and Larsson, 1982; Ahler, 1983; Hanckel, 1985; Rick and Chappell, 1983; Domanski and Webb, 1992; Domanski et al., 1994). Our experiments into the conditions of thermal damage, set out below, were designed to test claims that only slow and steady heating could avoid cracking and shattering. To evaluate these claims we carried out experiments using relatively rapid changes of temperature, an approach that Griffith et al. (1987) had previously employed in both laboratory and field conditions.

Curiously, while Crabtree and Butler's statements about appropriate heating procedures prompted extensive experimental investigations using similar methods, there was little further research into another factor that they recognized. They observed that the relative thickness of specimens affected the success of heat treatment, writing that "Spalls, cores, and roughed out blanks that are comparatively thin can be heat treated more successfully than thick chunks or nodules … . The thicker pieces do not heat or cool evenly and, as a result, crack or craze rather easily" (Crabtree and Butler, 1964, p. 2). Many experimental programs have sought to define the optimum temperature and length of time required to heat treat siliceous rocks, and observed that these varied between different materials, but these conclusions have not quantified how heating must be varied with specimen size if thermal fracture is to be avoided (Mandeville, 1973; Rick and Chappell, 1983; Bleed and Meier, 1980; Purdy, 1974; Schindler et al., 1982). We tested the effects that altering size had on the temperature at which a raw material fractured.

3. Conditions inducing thermal fracturing

Defining the conditions that create fractures in siliceous rocks placed under thermal stress is not a simple matter. Our experiments were conducted in controlled laboratory conditions, so that it was possible to measure the effects on thermal fracture of several variables. Our particular concern was to establish information about the relationships between temperature(s) at which siliceous, knappable rocks will thermally fracture, the speed of the heating event as well as the size of the specimen (measured as volume), and its petrological properties.

Two kinds of rock were employed in our experiments. The first was a silicified, fine tuffaceous mudstone from near Singleton in the Hunter Valley, New South Wales. It is comprised of finely microcrystalline chalcedony with a grain size of the chalcedonic silica of 0.002–0.004 mm. The second material was a silcrete from Bannister's Point on the New South Wales south coast, consisting of poorly sorted sub-angular and sub-rounded quartz grains 0.1–0.5 mm set in a finer siliceous matrix. Both rocks types are typical of the materials widely available in eastern Australia, and they were selected as proxies for chert- and quartzite-like rocks elsewhere in the world. Previous experiments indicate that every source of raw material may respond slightly differently when exposed to heat; our key interest was in establishing the relationships between these variables rather than identifying any universal temperature threshold.

Our experimental design was based on the proposition that there was minimal variation between different specimens of a single kind of rock material, an approach that focussed attention on the degree of difference in the response of different rock types to thermal stress. To ensure consistency within each rock type all experimental specimens of silcrete were cut from a single large block of stone displaying uniform characteristics. The specimens of silicified mudstone were obtained from a number of small cobbles and specimens from each were tested in identical conditions to establish that their reaction to thermal stress was identical.

All specimens were cut into rectangular prisms and cubes of various sizes using water-cooled diamond blade saws. Specimens were cut into five standard sizes: $10 \times 10 \times 10$ mm (1 cm^3), $20 \times 20 \times 10$ mm (4 cm^3), $20 \times 20 \times 20$ mm (8 cm^3), and $40 \times 40 \times 20$ mm (32 cm^3) and $40 \times 40 \times 40$ mm (64 cm^3). This created objects of different volumes and shapes, each represented by multiple specimens which were subjected to different heat conditions, establishing the interaction between these factors.

All specimens were tested in a Nabar electrical furnace. Temperatures employed in our experiments ranged from 500 to 1000 °C, as guided by the range of maximum temperatures that wood fires are capable of reaching (see Shepard, 1968; Mandeville, 1973; Griffiths et al., 1987; David, 1990; Robins and Stock, 1990), and the temperatures required to induce cracking and fracturing in the materials tested. The furnace precisely controlled the temperature to which each specimen was exposed (±5 °C). This could not be so easily achieved by using a 'real' wood fire (see Supplementary Appendix).

In these experiments no one specimen was used for a second heating event to ensure that any outcome could be attributed to the variable being tested and not to alterations in rock properties brought on by multiple heating events. All specimens were placed into the furnace without any insulation, such as a sand bath, and only a single specimen was heated at one time.

A pilot study on 4 cm^3 silcrete specimens determined that heating them gradually to excessive temperatures (>1000 °C) did not induce fracture, nor did removing specimens from the furnace at such high temperatures and rapidly exposing them to room temperature (20 °C). We therefore limited our main series of experiments to conditions in which fracture readily occurred: rapidly heating rock by taking a room temperature specimen and placing it into the furnace preheated to a designated maximum temperature less than 1000 °C. After 1 h the furnace was switched off and the specimen left to cool overnight.

Our experiments demonstrated that there were two temperature 'thresholds', which we defined by the level of macroscopically visible thermal damage exhibited by specimens, and three 'thermal response zones' bounded by these thresholds (Fig. 1). The 'intact zone' represented the temperature range within which specimens did not exhibit structural damage. It is only within this zone that successful heat treatment will occur, and potentially any temperature in the intact zone above 3–400 °C might have heat treated our specimens. The cracking threshold represented the upper limit of this zone. The 'cracking zone' corresponded to the temperature range between the cracking threshold and the fracture threshold. In this zone specimens showed thermal stress in the form of surface cracks but remained intact. Finally the 'fracturing zone' involved temperatures in excess of the fracture threshold which caused specimens to break into two or more fragments. Experimentally we could define the thresholds, and thus the zones bounded by them, within ±5 °C, and we could induce predictable responses by exposing specimens to set temperatures within the desired thermal response zone.

The temperature above which fracturing occurred in silcrete varied from 700 °C to 900 °C. Thermal responses displayed by specimens cannot be understood in terms of temperature alone; there is a clear and important interaction between temperature and specimen volume (Fig. 1). Both the cracking and fracture thresholds display an inverse, non-linear relationship between the size of the specimen and temperature. There is a strong ($r^2 = 0.96$) non-linear correlation between the fracture threshold and object size, described by the equation $y = 957.1 + (-71.6 \times \ln x)$, where y is the temperature (°C) at which the object fractures and x is the volume of the object in cubic centimetres. A similarly strong ($r^2 = 0.99$) non-linear correlation exists between the cracking threshold and object size, described by the equation $y = 724.3 + (-31.4 \times \ln x)$. The precise nature of these relationships is dependent on the raw material properties of the specimens (see below) among other factors, but we are confident that the interactions documented for eastern Australian silcrete will be found in many knappable sedimentary rocks elsewhere in the world.

A further interplay exists between raw material, temperature and specimen volume (Fig. 2). Singleton mudstone displayed a strong ($r^2 = 0.975$) relationship between fracture threshold and object size, as described by the equation $y = 766.7 + (-59.2 \times \ln x)$. The curves for mudstone and silcrete, describing the relationship between fracture temperature and object size, are extremely similar in shape, although the fracture threshold for mudstone is substantially lower, by more than 100 °C, than the silcrete fracture threshold. The similarities in shape between these two fracture thresholds leads us to predict that this interaction will be shared by many siliceous rocks, a hypothesis that can be further tested.

4. Interactions of experimental factors

These experiments indicate that thermal fractures can occur in different conditions, as a consequence of the interaction of several factors, and cannot be explained merely by reference to the application of high temperatures or a rapid rate of temperature change. Interactions established here provide a new understanding of the contexts of thermal shattering, which in turn help to define the contexts in which heat treatment may be successful.

There is an inverse non-linear relationship between specimen size and the temperature at which irreversible structural damage will occur. Large artefacts/objects will crack or fracture at lower temperatures than small ones. Consequently, the size of artefacts/objects exposed to heat for purposes of heat treatment will affect the probability of a successful outcome or the shattering of one or more specimens. Heat treatment of smaller specimens will therefore produce a lower failure rate than the heat treatment of large specimens, all else being equal, because the higher cracking and fracture thresholds of smaller specimens provides for greater tolerance in heat fluctuations during the heat treatment event. Archaeologically this might be visible for specimens that have been exposed to high temperatures, in the systematic size differences between objects that are heat damaged and those that are not, as well as between those that are cracked and those that are fractured into fragments. Furthermore, because of the influence that specimen size has on the temperature at which fracture occurs, knappers who were attempting to heat treat several specimens at the same time would have gained benefit if they were the same size, since this would increase the likelihood that they would all respond to heating in the same way.

Our experiments also reinforce the frequently made observation that the conditions in which thermal cracking or fracture will occur may differ between siliceous sedimentary rocks used in knapping because thermal response zones differ between rock types. In the experiments described here the fracture threshold differed by more than 100 °C for rocks used by prehistoric Australian knappers, and in North America far larger differences (up to 400 °C) between raw materials have been reported (e.g. Mandeville, 1973, p. 191; Luedtke, 1992, p. 93). The dissimilar response of each rock type to

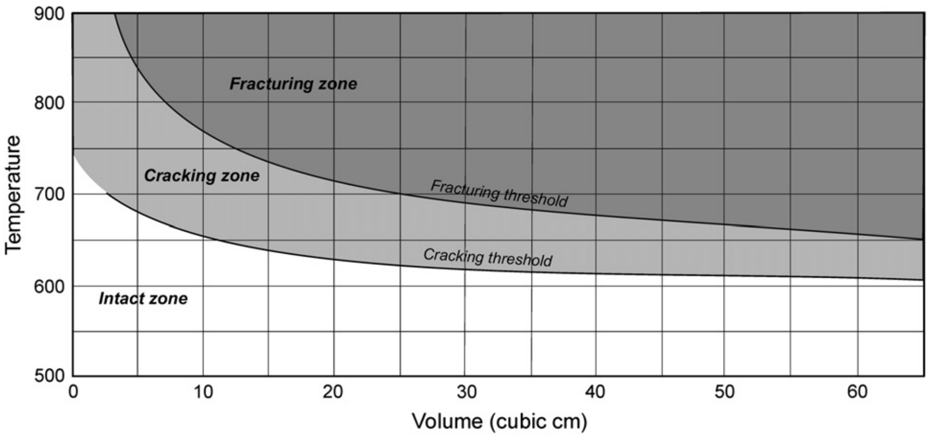

Fig. 1. Fracturing and cracking zones in Bannister silcrete, revealing the interaction between temperature and specimen volume. Curves are the non-linear lines-of-best-fit for the lowest temperatures at which macroscopic cracks of fractures formed.

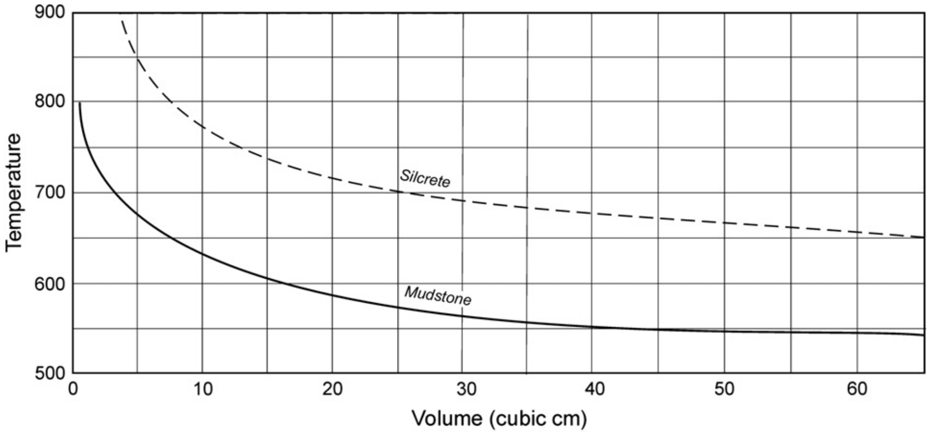

Fig. 2. Fracturing thresholds for Bannister silcrete and Hunter mudstone, revealing the interaction between temperature, specimen volume, and raw material. Curves are the non-linear lines-of-best-fit for the lowest temperatures at which fractures formed.

heat would, presumably, have been familiar to prehistoric knappers who would have benefited from heating specimens made from the same raw material in a single episode.

These experiments reinforce and amplify those of earlier researchers who recognized that heating siliceous material without causing it to fracture involved a balance between multiple factors that potentially create conditions in which fracture is unlikely. We argue that the precise outcome of heating knappable rock will be determined by the interaction between specimen volume and raw material as well as temperature and the rate of heating. The implications of this conclusion extend far beyond the truism that ancient knappers were skilled at the process, and provide the basis for a novel consideration of the strategies that might have been employed to heat treat rock while avoiding thermal shattering.

5. A consideration of alternative heat treatment strategies

Much of the literature exploring heat treatment is grounded in the idea that there is a set of 'best' methods for accomplishing the task, that these can be defined experimentally for any given rock type (e.g. Mandeville, 1973, p. 199), and that ancient knappers applied this recipe in heating their siliceous rocks. As we have discussed above many researchers have argued that improving the flakability of lithic material requires heating it for a considerable length of time to an optimum temperature to avoid damaging the rock. It has been argued that this necessarily involves careful and elaborate preparation and monitoring of the heating process. A dissenting view by Griffiths et al. (1987) is that such laborious practices were unnecessary, and that prehistoric knappers more often heated stone simply and rapidly. We argue that explaining all heat treatment events as the result of either rapid or slow heating is unjustified. Existing experimental evidence suggests more than one procedure could have been used and that it is possible that prehistoric people employed multiple strategies to heat treat their stone. These strategies can be thought of as a continuum of options that stretch between extremes.

At one extreme there is the oft cited strategy of heating and cooling specimens slowly, over long periods of time: the 'slow and steady' scheme mentioned earlier in this paper. As performed in many replication experiments in North America this strategy is time consuming and often labour intensive. In some experiments archaeologists took up to 48 h to heat material up and 20 h to cool it down (e.g. Ahler, 1983; Mandeville and Flenniken, 1974). Archaeologists have often replicated this 'slow and steady' approach by burying specimens in deep pits in which sediments such as sand buffer the heated artefacts from coals and/or fires. For example, Mandeville and Flenniken (1974, p. 146) constructed an elaborate heat treatment facility (Fig. 3A): a large pit approximately 70 cm deep, 60 cm in diameter and containing successive layers of charcoal and sand. The idea behind the elaborate context for heating

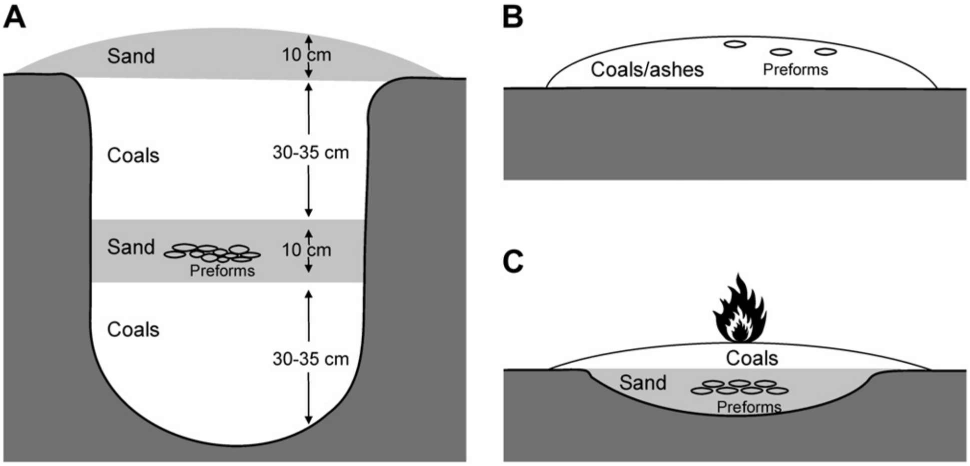

Fig. 3. Schematic illustrations of heat treatment processes discussed in the literature. (A) Deep pits with coals and buffering sands (after Mandeville and Flenniken, 1974). (B) Specimens dropped directly into cooling coals and ashes (after Griffiths et al., 1987). (C) Shallow pits immediately below small fires (after Griffiths et al., 1987).

was to ensure that temperature changes were gradual and that specimens were held at suitable temperatures for prolonged periods. For instance, Mandeville and Flenniken (1974, pp. 146–147) placed preforms in a matrix of sand to insulate them against the heat source, restricting the maximum temperature to 325 °C, and maintained it at that temperature for 1.5 h before 'a slow and gradual decent' that lasted for 20 h. Such a strategy could have been applied to both relatively large (>32 cm^3) and small specimens, and might have allowed specimens of quite different sizes and materials to be treated in a single heat treatment event.

At the opposite end of a continuum of thermal contexts we hypothesize heat treatment strategies that were faster and required less energy to be invested in construction of facilities or monitoring and maintaining fires. These 'fast' strategies placed specimens in close proximity to heat sources and allowed them to be heated relatively rapidly, for relatively short periods, to relatively high temperatures, often exploiting the higher fracture and cracking thresholds of small fragments to avoid detrimental outcomes. Griffiths et al. (1987, p. 45) documented improvements in flaking quality after only 30 min, concluding that specimens could be heat treated as well in short periods as they could in 24 h. They argued that as long as temperatures were not extreme enough to damage the specimens, heat treatment could be achieved rapidly and with minimum effort. Griffiths et al. (1987) experimentally tested some of the practices that could be employed, such as simply placing specimens into ashes as they are cooling (Fig. 3B). Even when buffering sediment was employed to protect specimens from the heat source, the effort involved in facility creation or monitoring might have been minimal. For example, burying specimens shallowly beneath a hearth (Fig. 3C) or caking them in clay might be sufficient precautions to ensure successful heat treatment (Griffiths et al., 1987). Such strategies would have required knowledge of the thermal responses of the raw materials being treated and of the appropriate heat levels that could be used, but there is no evidence that they were necessarily more risky than alternative 'slow and steady' strategies. We suggest that a crucial component in the success of these 'fast' strategies may have been the capacity of knappers to attain some control over the outcomes of the process through standardization of specimen size as well as the production of a physical context for heating. In particular we note that blank or preform size could be controlled more precisely than can temperature during the heating event, and that in the absence of elaborate heating facilities knappers employing the 'fast' strategy could have affected the response of specimens to heating by the production/selection of specimens of specific sizes. For this reason we hypothesize that a crucial component in the success of these 'fast' strategies may have been the standardization of specimen sizes and shapes as well as the utilization of the greater resilience of smaller specimens to high temperatures. By exposing relatively small specimens of regular and appropriate sizes to specific heating conditions knappers would have been able to decrease the likelihood of thermal damage thereby increasing the probability of achieving successful heat treating. Consequently when several specimens were treated in a single heat treatment event there would have been a benefit in having specimens of very similar sizes and materials, and for them to be as small as possible.

The choice of which heat treatment strategy would have been most beneficial to knappers at any specific place or period probably involved a consideration of not only the constraints imposed by the properties of stone materials and the mechanics of the heating process, but also the articulation of heat treatment activities with the broader system of technology and economy. Heat treatment strategies, like other aspects of stoneworking technology, would have been connected to the economic context in which stone tools were made and used. However, discussions of technological responses to different economic contexts have not previously considered these alternative heat treatment strategies. Explication of the relationships of Palaeolithic technology and economy have increasingly focussed on the ways in which tool production and use reflected factors such as mobility, time stress, raw material replacement costs, and foraging risk (e.g. Ebert, 1979; Torrence, 1983, 1989; Shott, 1986; Parry and Kelly, 1987; Jeske, 1989; Nelson, 1991; Bousman, 1993; Kuhn, 1995; Bamforth and Bleed, 1997; Hiscock, 2006). While we do not have space to fully explore the role of such factors in the selection of a heat treatment strategy we can sketch some of the more obvious economic connections. For instance, when groups were residentially highly mobile, encountering scheduling difficulties, unable to plan tool production long in advance of anticipated need, in regions with abundant suitable rock for knapping, or requiring heat treatment of only small pieces of rock, the labour and time saving conferred by a 'fast' strategy may have been preferred. However when groups were more sedentary, had to obtain replacement lithic materials through logistic forays to distant locations or via exchange, could produce tools long in advance of need, required larger-scale production and/or large preforms to be heat treated, or were processing rock types that were especially prone to thermal shock, the labour and time of large facility construction and slow, careful heating may have been preferred. Further experimental characterization of the cost and success rates of different heat treatment strategies should assist in building more detailed models of the economic context of these activities.

The articulation of different heat treatment strategies with systems of economy and land use has the potential to explain some spatial and chronological variability in archaeological debris. For instance, it has been suggested that the use of shallow pits packed with clay to heat treat small silcrete retouched flakes is a late Holocene innovation in the southeast of Australia (McDonald and Rich, 1994). Since heat treatment of silcrete has been practiced in this region for at least the last 25,000 years (Hanckel, 1985) the abundance of heat treatment pits in the last 1500 years is not a result of the local introduction of heat treatment practices and may instead reflect a shift in the strategy for altering stone, towards pit construction and 'slow' strategies as somewhat more logistically structured landscape use developed (see Attenbrow, 2004; Hiscock, 2008). The production practices commonly employed in southeastern Australia prior to 1500 bp, during the middle- and late-Holocene, involved the heat treatment of small rock specimens (typically less than 20–30 cm^3) such as mudstone and silcrete burinated retouched flakes with standardized sizes, often in batches of nearly identical specimens (e.g. Hiscock, 1993; Hiscock and Attenbrow, 2005), a pattern that would have been extremely suitable for the employment of 'fast' heat treatment strategies.

6. Conclusions

These experiments have exposed the complexity of relationships between factors involved in causing thermal damage in siliceous rocks, and allowed us to evaluate existing claims of how heat treatment could have been undertaken in the past. In this paper we present data which demonstrate that specimen size affects the temperature at which material used by prehistoric knappers will suffer thermal damage. One consequence of this finding is that no single 'critical temperature' for thermal fracturing or heat treatment can be specified for any particular raw material, as has so often been attempted, because threshold temperatures exist only in relationship to specimen sizes.

The multi-factorial causes of heat-induced fracturing have implications for archaeological thinking about the heat treating process. For many materials there is more than a single combination of variables that enable lithic specimens to be heat treated. We have discussed this in terms of a continuum of heat treating strategies; a continuum between the ‘slow and steady’ strategy which has overwhelming dominated past experimental designs and the ‘fast’ strategy which has received much less attention. Our experiments have shown that smaller specimens are resilient to greater ranges of temperature fluctuations than larger ones, and that by manufacturing/selecting specimens of smaller sizes there is more potential to heat them rapidly and to higher temperatures without producing thermal fractures. In light of this evidence we propose that both slow and fast strategies of heat treatment were used in the ancient past, and that the diversity of heat treatment strategies reflects the diversity of raw material responses to heat, the variety of technologies in which heat treatment was employed, and the range of economic contexts in which ancient humans operated.

Appendix A. Supplementary material

Supplementary information for this manuscript can be downloaded at 10.1016/j.jas.2008.04.021.

References

Ahler, S.A., 1983. Heat treatment of Knife River flint. Lithic Technology 12, 1–8.

Attenbrow, V., 2004. What’s Changing: Population Size or Land-Use Patterns? The Archaeology of Upper Mangrove Creek, Sydney Basin. Pandanus Books, Canberra.

Bamforth, D.B., Bleed, P., 1997. Technology, flaked stone technology, and risk. In: Barton, C.M., Clarke, G.A. (Eds.), Rediscovering Darwin: Evolutionary Theory and Archaeological ExplanationArchaeological Papers of the American Anthropological Association No. 7, pp. 109–139.

Bleed, P., Meier, M., 1980. An object test of the effects of heat treatment of flakable stone. American Antiquity 45, 502–505.

Bousman, C., 1993. Hunter-gatherer adaptations, economic risk, and tool design. Lithic Technology 18, 59–86.

Crabtree, D.E., Butler, B.R., 1964. Notes on experiments in flint knapping: 1. Heat treatment of silica minerals. Tebiwa 7, 1–6.

David, B., 1990. How was this bone burnt? In: Solomon, S., Davidson, I., Watson, D. (Eds.), Problem Solving in Taphonomy: Archaeological and Palaeontological Studies from Europe, Africa, and Oceania. Anthropology Museum. The University of Queensland, Brisbane, pp. 65–79.

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.

Domanski, M., Webb, J.A., Boland, J., 1994. Mechanical properties of stone artefact materials and the effect of heat treatment. Archaeometry 36, 177–208.

Ebert, J.I., 1979. An ethnoarchaeological approach to reassessing the meaning of variability in stone tool assemblages. In: Kramer, C. (Ed.), Ethno-Archaeology: Implications of Ethnography for Archaeology. Columbia University Press, pp. 59–74.

Flenniken, J.J., Garrison, E.G., 1975. Thermally altered Novaculite and stone tool manufacturing techniques. Journal of Field Archaeology 2, 125–131.

Griffiths, D.R., Bergman, C.A., Clayton, C.J., Ohnuma, K., Robins, G.V., Seeley, N.J., 1987. Experimental investigations of the heat treatment of flint. In: Sieveking, G. De. G., Newcomer, M.H. (Eds.), The Human Uses of Flint and Chert. Cambridge University Press, Cambridge, pp. 43–52.

Hanckel, M., 1985. Hot rocks: heat treatment at Burrill Lake and Currarong, New South Wales. Archaeology in Oceania 20, 98–103.

Hiscock, P., 1993. Bondaian technology in the Hunter Valley, New South Wales. Archaeology in Oceania 28, 65–76.

Hiscock, P., 2006. Blunt and to the point: changing technological strategies in Holocene Australia. In: Lilley, I. (Ed.), Archaeology in Oceania, Australia and the Pacific Islands. Blackwell, pp. 69–95.

Hiscock, P., 2008. Archaeology of Ancient Australia. Routledge.

Hiscock, P., Attenbrow, V., 2005. Australia’s Eastern Regional Sequence Revisited. Technology and change at Capertee 3. BAR International Series 1397. Archaeopress, Oxford.

Jeske, R., 1989. Economies in raw material use by prehistoric hunter-gatherers. In: Torrence, R. (Ed.), Energy and Stone Tools. Cambridge University Press, Cambridge, pp. 34–45. Time.

Joyce, D.J., 1985. Heat treatment of Alibates chalcedony. Lithic Technology 14, 36–40.

Kuhn, S.L., 1995. Mousterian Lithic Technology. Princeton University Press, Princeton, NJ.

Luedtke, B.E., 1992. An Archaeologist’s Guide to Chert and Flint. Archaeological Research Tools 7. Institute of Archaeology. UCLA, Los Angeles.

McDonald, J., Rich, B., 1994. The discovery of a heat treatment pit on the Cumberland Plain, Western Sydney. Australian Archaeology 38, 46–47.

Mandeville, M.D., 1973. A consideration of the thermal pretreatment of chert. Plains Anthropologist 18, 177–202.

Mandeville, M.D., Flenniken, J.J., 1974. A comparison of the flaking qualities of Nehawka chert before and after thermal pretreatment. Plains Anthropologist 19, 146–148.

Mercieca, A., 2000. Burnt and broken: an experimental study of heat fracturing in silcrete. Australian Archaeology 51, 40–47.

Nelson, M., 1991. The study of technological organization. Archaeological Method and Theory 3, 57–100.

Olausson, D.B., Larsson, L., 1982. Testing for the presence of thermal pretreatment of flint in the Mesolithic and Neolithic of Sweden. Journal of Archaeological Science 9, 275–285.

Parry, W.J., Kelly, R.L., 1987. Expedient core technology and sedentism. In: Johnson, J. K., Morrow, C.A. (Eds.), The Organization of Core Technology. Westview Press, Boulder, CO, pp. 285–304.

Pavlish, L.A., Sheppard, P.J., 1983. Thermoluminescent determination of Paleoindian heat treatment in Ontario, Canada. American Antiquity 48 (4), 793–799.

Patterson, L.W., 1995. Thermal damage of chert. Lithic Technology 20, 72–80.

Price, T.D., Chappell, S., Ives, D.J., 1982. Thermal alteration in Mesolithic assemblages. Proceedings of the Prehistoric Society 48, 467–485.

Purdy, B.A., 1974. Investigations concerning the thermal alteration of silica minerals: an archaeological approach. Tebiwa 17, 37–66.

Purdy, B.A., 1975. Fractures for the archaeologist. In: Swanson, E.H. (Ed.), Lithic Technology. Mouton, Chicago, IL, pp. 133–144.

Purdy, B.A., Brooks, H.K., 1971. Thermal alteration of silica materials: an archaeological approach. Science 173, 322–325.

Rick, J.W., Chappell, S., 1983. Thermal alteration of silica materials in technological and functional perspective. Lithic Technology 12, 69–80.

Robins, G.V., Seeley, N.J., McNeil, D.A.C., Symons, M.R.C., 1978. Identification of ancient heat treatment of flint artefacts by ESR spectroscopy. Nature 276, 703–704.

Robins, R.P., Stock, E.C., 1990. The burning question: a study of molluscan remains from a midden on Morton Island. In: Solomon, S., Davidson, I., Watson, D. (Eds.), Problem Solving in Taphonomy: Archaeological and Palaeontological Studies from Europe, Africa, and Oceania. Anthropology Museum, The University of Queensland, Brisbane, pp. 80–100.

Rowney, M., White, J.P., 1997. Detecting heat treatment on silcrete: experiments with methods. Journal of Archaeological Science 24, 649–657.

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.

Shepard, A.O., 1968. Ceramics for the Archaeologist, sixth ed. Carnegie Institution of Washington, Washington, DC.

Shott, M.J., 1986. Technological organization and settlement mobility: an ethnographic examination. Journal of Anthropological Research 42, 15–51.

Torrence, R., 1983. Time budgeting and hunter-gatherer technology. In: Bailey, G. (Ed.), Hunter-Gatherer Economy in Prehistory. Cambridge University Press, Cambridge, pp. 11–22.

Torrence, R., 1989. Tools as optimal solutions. In: Torrence, R. (Ed.), Time, Energy and Stone Tools. Cambridge University Press, Cambridge, pp. 1–6.