# Burnt and broken: An experimental study of heat fracturing in silcrete

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Heat-induced fracturing of archaeological stone is a worldwide phenomenon, yet it is poorly understood. Not only does confusion surround the common perception of heat fracturing, where it is often confused with heat-treating, but our knowledge of the specific processes responsible for heat fracturing has been retarded by a lack of explicit and controlled experimental investigation. Apart from two North American experimental studies (Purdy 1974, 1975; Patterson 1995), no published and/or widely available experimental data on heat fracturing of archaeological stone material exists.

In the absence of a sound experimental basis, unsubstantiated and untested explanations have been invoked to account for the archaeological presence of heat fractured stone. The research described in this paper sets out to clarify the distinction between heat-treating and heat fracturing before providing some experimental evidence of the conditions in which heat fracturing occurs. This evidence is subsequently used to develop taphonomic principles of heat-induced fracturing. These principles can be used when developing archaeological explanations for sites featuring stone material displaying heat-induced fracturing. The paper concludes with examples that highlight the significance such research has for archaeologists.

**Heat fracturing: Its definition and archaeological scope**

It is necessary to begin with an acknowledgement that heat fracturing is not necessarily associated with the practice of heat-treating. It is therefore inappropriate to use the two terms interchangeably; the two concepts are not one and the same, nor are they necessarily connected. For this reason it is important to first define each concept in order to avoid any confusion. This will also serve to establish the intended meaning of both terms for this paper.

*Heat-treating* occurs when stone material is heated in a controlled manner, prior to or during various stages of the knapping process, to produce a material that is comparatively homogeneous to its unheated counterpart. A practice known to have been globally employed by prehistoric flintknappers (Hester 1972; Collins and Fenwick 1974; Flenniken and Garrison 1975), including in Australia (Akerman 1979; Flenniken and White 1983; Hanckel 1985; Domanski and Webb 1992; Rowney and White 1997), heat-treating requires specific temperatures and timing, with experiments having demonstrated that exceeding these critical conditions (for example too high a temperature, or heating or cooling too rapidly) often results in fractures (Purdy and Brooks 1971:323; Purdy 1974:40; Purdy 1975:137; Patterson 1995:73). When successful however, the result is an increased ease in flaking of the stone material (Crabtree and Butler 1964:1; Purdy and Brooks 1971:325; Domanski *et al* 1994:178). Furthermore most archaeologists use the term heat-treating to imply intent. Incidentally, although a deliberate act, quarrying with fire is not included in this definition of heat-treating by most archaeologists because it is not specifically intended to alter the flaking properties of the stone in order to improve flakability (Gregg and Grybrush 1976:189; Akerman 1979:144). Fire-cracked rock and boiling stones are thus also excluded for the same reasons.

On the other hand the term *heat fracturing* indicates that a piece of stone has suffered physical stress (in the form of such fractures as crenation, potlidding, and surface crazing) produced through heat. This heat stress occurs as *cracking* and/or *shattering* of the stone, where *cracking* implies that although physically damaged, the stone remains in one piece, whereas *shattering* results in two or more pieces. Heat fracturing effects artefactual as well as non-artefactual stone material as there is no assumption that fracturing resulted through intended acts.

At present two explanations are usually offered by archaeologists for the presence of heat fractured stone in archaeological contexts. The first explanation perceives of heat fractures as the result of failed attempts to heat treat (Purdy and Brooks 1971; Collins and Fenwick 1974:136; Purdy 1975:133; Olausson and Larsson 1982:278). These fractures, although associated with attempts to heat treat, are still a separate component of that practice itself, simply representing one possible outcome. If the evidence suggests that this does appear to be the case, and the fractures are interpreted as the results of failed heat-treating attempts, then the heat fractured rock could possibly indicate the presence and location of a heat-treating pit at a site (McDonald and Rich 1994).

However, heat fracturing is not necessarily associated with heat-treating. An alternative explanation sometimes offered by archaeologists considers heat fracture initiation as resulting from proximity to other heat sources (Hiscock 1985; Hiscock and Hall 1988a:65; Hiscock 1993:67; Rondeau 1995:135-136). For example if artefacts happen to come into contact with a hearth employed for heat, light, and/or cooking upon or after deposition, any resulting heat fracturing would not be related to attempts at heat-treating. Heat fractured stone found at a site under these circumstances then may indicate the presence and location of a hearth, or hearth based activities at a site (Hassan 1987:4; Hall and Hiscock 1988:59; Hiscock 1993:67). Consideration should also be given to non-cultural heat sources such as bushfires as being the agent in heat fracturing archaeological stone.

Both explanations above essentially involve taphonomic processes where stone material is altered when heat is applied by a fire. So while both explanations for the heat-induced fracturing of archaeological stone are plausible, they are potentially weakened by a lack of principles developed through, and supported by, substantive experimental evidence. As pointed out by Tringham (1978:176) "Archaeologists tend to avoid doing the basic analysis and testing of the properties of archaeological materials themselves." Initially then, research should focus on acquiring knowledge of the processes responsible for transforming archaeological stone through heat-induced fracturing. The aim is to develop, from experimental observation, a sound body of taphonomic principles designed to

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help archaeologists interpret heat-induced fractured stone in the archaeological record. In doing so, such principles contribute to the overall theory of archaeological formation processes. Once we understand how stone responds to heat stress, we can then start to build inferences of site function and human behaviour.

**Experimental program**

The remainder of this paper presents research in which I considered how silcrete could be physically transformed through heat-induced fractures (Mercieca 1999). My overall goal was to investigate some of the cause-and-effect relationships behind the heat fracturing of stone material, with the purpose of developing some basic principles useful for archaeological interpretations. This I did through a series of laboratory experiments. Some of the results of these experiments are reported on in this paper, together with a brief consideration of their archaeological implications.

***Experimental aims***

The experiments outlined in this paper set about addressing the following questions:

- What are the heating conditions under which heat fracturing in stone is initiated?
- Does changing size of the specimens, while keeping all other known variables constant, affect these conditions?
- Does increased moisture content in specimens of the same size and shape affect these conditions?
- Is there a significant relationship between the number of fractures and the temperature to which specimens possessing the same attributes are exposed?

The experiments were also designed to either support or reject the following hypotheses, which were devised after reviewing the experimental data available in the literature. All hypotheses assume that all known extraneous variables are held constant:

- Sudden and extreme changes in temperature will cause stone material to fracture
- Increasing the size of the stone specimens will decrease the temperature required to initiate fracturing
- Increasing moisture content of the stone specimens will decrease the temperature required to initiate fracturing.
- The number of fractures created on specimens with the same attributes will increase as the temperature to which they are exposed increases.

***Equipment and materials***

These concerns were approached through a series of laboratory experiments at the Australian National University using the School of Archaeology and Anthropology's Nabar electrical furnace. Use of the furnace was considered the most effective way of controlling heating conditions, giving efficiency to a programme running on limited time and resources. Knowledge of the nature of wood fires gained through field experiments, such as the realistic range of potential maximum temperatures, was incorporated into the experimental design in order to ensure the results had archaeological relevance. This information is listed in Table 1.

The experimental specimens were prepared into rectangular prisms and cubes of various set sizes (20x20x10mm; 20x20x20mm; 40x40x20mm) using water-cooled diamond blade saws in the Geology Department at the ANU. Cutting the specimens using the saws provided a straightforward and convenient way of controlling and systematically altering the size and or shape of specimens so that the effects of manipulating such attributes could be observed.

The choice of size was based on three main factors:

1. Examples of the sizes of silcrete artefacts in archaeological context from around Australia were drawn from the literature (Byrne 1980; Hiscock 1982).

Specific examples include Hiscock and Hall (1988a: 78) who provide the following range of dimensions for unretouched silcrete flakes >5mm recovered from Platypus Rockshelter in southeast Queensland: Length = 7-46mm; Width = 10-31mm; Thickness = 2-9mm. Another example comes from Sandy Hollow Rockshelter in the Hunter Valley. These measurements come from artefacts located in Spit 2 of that site (Hiscock 1986:43): Length = 4-58mm; Width = 1-42mm.

2. The availability of raw material for producing experimental specimens: the choice of specimen size was partially dictated by the size of the available silcrete cobbles.
3. Restrictions imposed upon the cutting process by the saws used, where cutting anything thinner then 10mm caused the rock to slip, proving hazardous to the blade, and endangering my fingers.

There are two main groups of variables that play a part in creating heat fractures in stone. These will be called 'specimen variables' and 'environmental variables'. Specimen variables are attributes pertaining to the specimen itself, such as raw material, size, shape, and moisture content. Environmental variables are those external to the specimen, such as timing (rate of heating and cooling; time at maximum temperature) and temperature (starting, maximum, finishing) of exposure. Previous heat fracturing experiments (Purdy 1975; Patterson 1995) have focused on manipulating the variables within the latter group, as have the majority of heat-treating experiments from which we get a scattering of additional information on heat fracturing (e.g. Crabtree and Butler 1964; Price *et* al 1982; Ahler 1983; Joyce 1985; Griffith *et al* 1987). In focusing on the effects of environmental variables on the heating of stone, these experiments have largely neglected to either control for or isolate and test for variation within the specimens themselves. This potentially weakens any principles developed, particularly if limited control is kept over known extraneous specimen variables (whilst testing for the effects of altering timing and

| Wood type | Maximum Temp°C | Time (min) to reach max temp | Reference |
|---|---|---|---|
| *Juniperus* sp. | 962 | 25 | Shepard (1968) |
| Carpenter's scrap | 805 | 210 | Mandeville (1973) |
| Various deciduous species | 540(still day) 700 (windy) | ? | Griffith *et al* (1987) |
| *Eucalyptus macrorhyncha* and *E. rossii* | 840 | 5 | David (1990) |
| *Causuarina littoralis* | 860-870 | ? | Robins and Stock (1990) |

**Table 1** Maximum temperatures obtained and the time taken to reach maximum temperature in experimental fires of various woods.

temperature). Because of this imbalance, I set out to control for and also test the influence of some specimen attributes on the heat-induced fracturing of stone. The experimental programme, with its results, is summarised in Table 2.

All specimens used in the experiments were cut from a single silcrete cobble collected from Bannister's Point on the New South Wales south coast. In this way possible variation within a single petrological class was controlled for. Furthermore each specimen was only used for a single heating event so that any reaction could be attributed to the testing variable, and not to the fact that the specimen may have been weakened by multiple heating events. Finally all specimens were placed into the furnace without any insulation to simulate some aspects of direct exposure of the stone to fire.

***Methods and results***

*Testing variables within the heating conditions*

Initial experimentation focused on the heating conditions necessary to initiate fracturing. This involved the sudden heating and cooling of specimens (20x20x10mm). In the former case, the specimens were taken from room temperature and placed into a furnace preheated to temperatures ranging from 635-995°C. The specimens were then left at this

| Set | No. of Species | Test | Size (mm)* (within set) | Constants (within set) | Test variable | Result |
|---|---|---|---|---|---|---|
| 1 | 18 | Effects of suddenly exposing a *dry* specimen to preheated furnace | 20x20x10 | Size; shape; pre-test treatment (dry); time at max temp; cool down time; finish temperature | Maximum temp/ starting temp | Fracturing |
| 2 | 14 | Effects of suddenly exposing a *soaked* specimen to preheated furnace (increased moisture content) | 20x20x10 | Size; shape; pre test treatment (soaked); time at max temp.; cool down time; finish temp. | Maximum temp./ starting temp. | Fracturing |
| 3 | 7 | Effects of suddenly exposing a dry specimen to preheated furnace (increased size and shape) | 20x20x20 | Size; shape; pre-test treatment (dry); time at max temp.; cool down time; finish temp. | Maximum temp./ starting temp. | Fracturing |
| 4 | 4 | Effects of suddenly exposing a dry specimen to a preheated furnace (increased size) | 40x40x20 | Size; shape; pre-test treatment (dry); time at max temp.; cool down time; finish temp. | Maximum temp./ starting temp. | Fracturing |
| 5 | 15 | Effects of suddenly removing specimen from furnace at max temp to room temp | 20x20x10 | Size; shape; starting temp. | Maximum temp./ finishing temp.; rate of heating | No physical damage |
| 6 | 3 | Effects of suddenly removing specimen from furnace at max temp and immersing in water | 20x20x10 | Size; shape; starting temperature | Maximum temp/ finish temp; rate of heating | No physical damage |
| 7 | 1 | Effects of exposing specimen to extended periods of heating | 20x20x10 | n/a# | n/a# | No physical damage |
| 8 | 1 | Effects of removing spec from furnace at max temp and then dripping water onto its surface | 20x20x10 | n/a# | n/a# | No physical damage |

*Size was varied between sets, not within, where it was held constant.
# no constants and variables because only one heating event was performed in the set.

**Table 2** Summary of experimental program and results obtained.

maximum temperature for 1 hour before the furnace was switched off and the specimen allowed to slowly cool down to the minimum temperature of the furnace. When suddenly cooled, specimens were heated up in the furnace to maximum temperature over a 12-hour period before being suddenly exposed to the ambient temperature (Set 5) or cold tap water at 16°C (Set 6).

This test produced a very distinct pattern. When suddenly heated, specimens began to crack at 675°C. In marked contrast, the sudden cooling of specimens, either through exposure to air temperature or cold water, failed to initiate heat fracturing. Furthermore, contrary to the results of previous experimentation (Mandeville 1973: 181; Purdy and Brooks 1971:323), no fracturing resulted when water was dripped onto the hot surface of the rock. Incidentally this procedure also failed to cause the material to chip or flake, the typical result of such tests designed to replicate ethnographic descriptions and historical observations (e.g. Nagle 1948:140). Given that fracturing was only achieved by sudden heating, and due to the limited opportunity to carry out an extensive experimental program in the allotted time, I decided to cease experimenting with the cool down process. The remainder of the experimental program thus focused on the effects of sudden heating when varying specimen attributes.

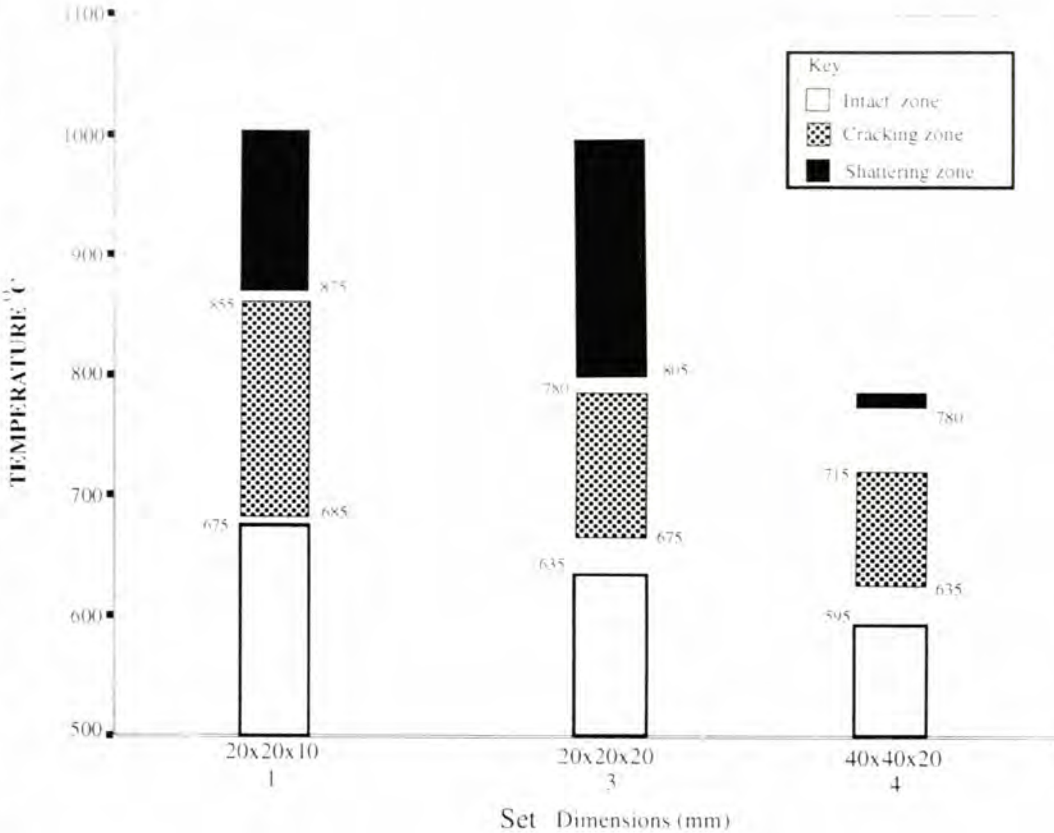


**Figure 1** Fracture thresholds (intact/cracking and cracking/shattering) for Sets 1, 3, and 4 showing the effect of increasing size on temperature required for fracturing.

However, prior to describing the results of the experiments where specimen attributes were varied, it is worth while noting that very limited experimentation testing the effects of prolonged exposure (8 days) to heat of stone at a relatively low temperature (525°C) also failed to produce fracturing. This result suggests that regardless of how long stone is exposed to heat stress, it will not fracture unless temperature is excessive enough. This tentative suggestion waits further testing.

*Effects of increasing specimen size*

Size of specimens was increased to 20x20x20mm (Set 3) and 40x40x20mm (Set 4) in order to test its influence on initiating heat fractures. Fig. 1 depicts the fracture thresholds for specimens of the three different sizes. Some thresholds are more precisely defined then others, purely due to the number of experimental events carried out within that set. For each set there are three zones, representing differences in the severity of damage experienced by specimens, and two thresholds, representing the temperature zone within which there is a transition from one physical state to the next. The lowest zone represents the temperature range within which no physical damage occurred on the specimens. The middle zone represents the temperature range within which cracking only occurred (i.e. damage, but specimen remaining whole), and the upper most bar represents

| Stage in heating event | Statistic | Weight (gms) | |
|---|---|---|---|
| | | Dry (Set 1) | Soaked (Set 2) |
| | N | 16 | 12 |
| Post-soaking/ Pre-heating | Mean | 11.356 | 12.433 |
| | Minimum | 10.3 | 11 |
| | Maximum | 12.8 | 13.8 |
| | Std. Dev. | 0.62 | 0.72 |
| Pre-soaked | Mean | n/a | 11.908 |
| | Minimum | n/a | 10.5 |
| | Maximum | n/a | 13.4 |
| | Std. Dev. | n/a | 0.73 |
| Post-heating | Mean | 11.338 | 11.858 |
| | Minimum | 10.3 | 10.4 |
| | Maximum | 12.7 | 13.3 |
| | Std. Dev. | 0.60 | 0.73 |

**Table 3**: Weight of specimens in Sets 1 and 2 at various stages in the heating process.

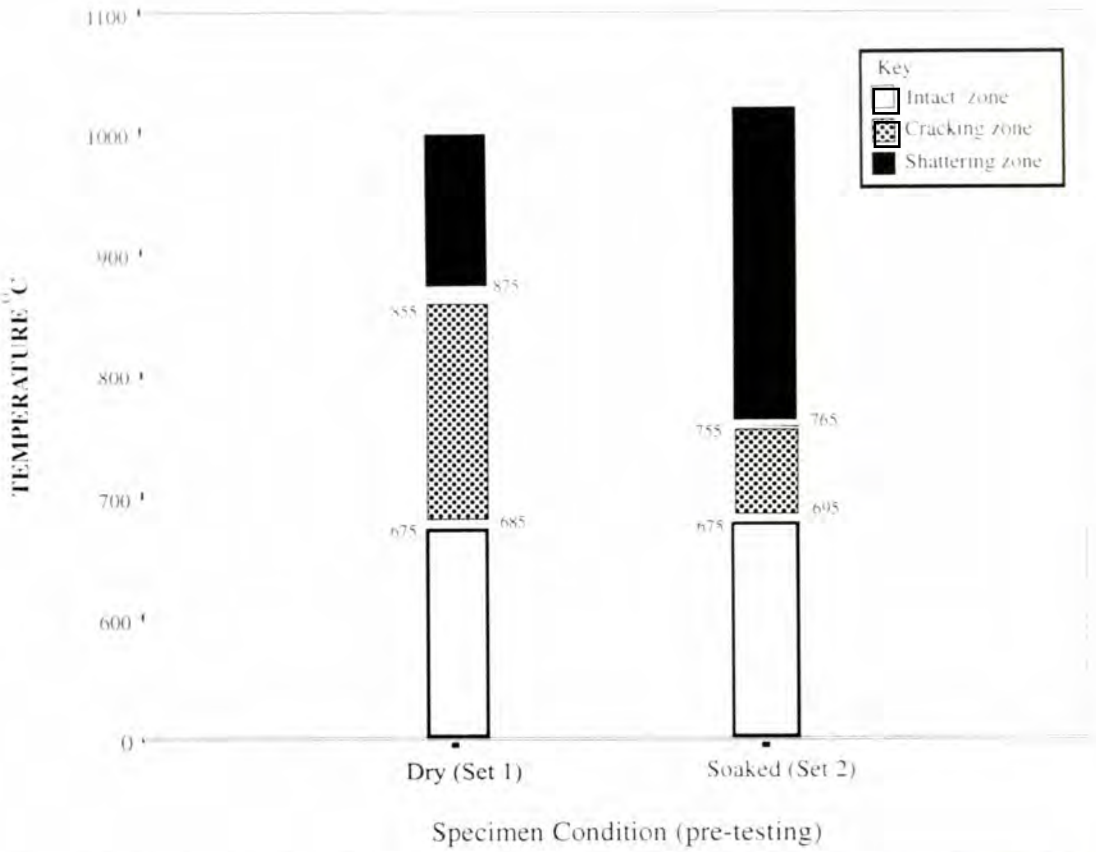


**Figure 2** Fracture thresholds (intact/cracking and cracking/shattering) for Sets 1 and 2 showing effect of increased moisture content on the temperatures required for fracturing.

the shattering zone, or the temperature range within which damage to the specimens caused them to break into two or more pieces. Thus the two thresholds represent the transition between no physical damage and cracking, and cracking and shattering. It should be noted that cracking and shattering actually lie on a continuum, i.e. it is very reasonable to expect cracks to eventually shatter through. This distinction was created purely as a means of describing the degree of severity of fracturing. It should also be noted at this point that although potlidding is one of the most commonly referred to heat fractures in the archaeological literature (Purdy 1975; Patterson 1995) none were present on any specimen exposed to any of the heating conditions tested during these experiments. Any shattering that did occur caused the stone to either break up into blocky angular pieces, or to 'exfoliate' – an 'onion peel-like' shatter where a concaved piece was removed from the corners and edges of the specimen.

Clearly evident in Fig. 1 is the effect of increasing specimen size: the larger the specimen, the lower the temperature required to initiate fracturing when stone is suddenly exposed to heat. In other words there is an inverse relationship holding between specimen size and the temperature required to initiate fracturing.

*Effects of increasing moisture content*

The effects of varying moisture content within specimens of the same size and shape was tested by soaking one group of 20x20x10mm specimens in water for at least 30 days (Set 2) and using an untreated, or control group, called the 'dry' set, as a comparison (i.e. Set 1). All specimens were suddenly exposed to the furnace, which had been preheated to temperatures ranging from 655-1010°C. To monitor moisture content, all soaked specimens were weighed on three occasions: before soaking, post soaking/pre heating, and post heating. The weights for each stage are listed in Table 3.

The increase in weight between pre and post soaking equaled the decrease in weight between pre and post heating, thus any weight gain or loss here appears to be the result of moisture movement into and out of the specimen. In comparison, there was no significant difference in the weight of dry specimens between pre and post heating. In short dry specimens cannot get any dryer, whereas soaked specimens can loose the extra moisture. This suggests that while moisture escaping from the soaked specimens could play a key part in causing those specimens to fracture, the same cannot be said of the dry specimens.

Comparing the results of the dry and soaked groups produced an intriguing pattern, as shown in Fig. 2. While moisture has a profound effect on causing stone to shatter, there is very little difference in the temperature required to initiate cracking between the two groups. The explanation of this apparent discrepancy awaits further study.

*Temperature vs number of fractures*

An additional aim of the experimental program was to assess whether there was a significant relationship between the number of fractures (cracks and shatters combined) and the temperature to which the rock was exposed. To answer this question, statistical tests were carried out on the results obtained for Set 1 (i.e. the dry 20x20x10mm specimens) only. Sample numbers prevented similar tests to be carried out on the remaining sets, but a glance over the raw data suggested that a similar pattern was emerging.

The statistical data indicates that the relationship between temperature and number of fractures is strongly correlated. That is according to Pearson's r at the 0.95 confidence level, there is less then 1% chance that the correlation is simply a product of sampling. The relationship between temperature and the number of fractures is also illustrated by the graph in Fig. 3, which shows that an increase in temperature resulted in an increase in the number of fractures.

*Taphonomic principles*

These results can be summarized into the following principles for heat-induced fracturing of archaeological stone. These principles also serve to address the questions and hypotheses formulated above:

1. Specimens (in this case silcrete), regardless of attributes, will only fracture if suddenly exposed to a temperature above a certain threshold. Extended periods of heating, and sudden cooling, either by exposure to air or water, failed to produce fracturing in the stone.
2. Increasing specimen size reduces the resistance of the rock to heat fracturing when suddenly exposed to heat as indicated by the lower temperatures necessary to initiate fracturing in larger specimens.
3. Increasing moisture content of specimens decreases the temperature required to shatter stone material (but not necessarily crack it) when it is suddenly exposed to heat.
4. There is a highly correlated relationship existing between increased temperature and an increased number of fractures.

**Implications and future directions**

To test the above taphonomic principles archaeologically was beyond the scope of this research, however the intention is to do so in the future. Nevertheless, these taphonomic principles carry with them a number of implications that affect the way in which heat fractures are used in archaeological interpretations. This applies not only to newly found, and yet to be interpreted sites and collections, but also to existing explanations, where new knowledge of heat fractures may lead to changes in interpretation. For example if artefacts were fragmented by heat stress, overestimations of artefact numbers may occur if each fragment is counted as representing a single artefact (Hiscock 1985:85). Alternatively artefacts may not be identified as such if their morphology is sufficiently altered by heat induced fractures unfamiliar to the archaeologist, that is the archaeologist is unaware of the various forms fractures occur as, and the resulting transformations caused to stone material by the fractures. This may result in underestimations of artefact numbers (Hiscock and Hall 1988a:65). Re-examination of assemblages has demonstrated how over and under estimations of artefact numbers at sites have occurred (see Hiscock 1985; Hiscock and Hall 1988b), which in turn can lead to inaccurate explanations of behaviour. For example the number of knapping events at a site or the intensity of site use (Hiscock 1985:85-86) could be downplayed or exaggerated.

Adequate knowledge of heat-induced fractures, in terms of both their visible archaeological signatures and the responsible taphonomic processes, can improve our ability to develop sound behavioural explanations. To do this, the following points should be kept in mind:

- That by definition heat fracturing and heat-treating of stone material are not the same thing, and therefore these terms should not be used interchangeably. Furthermore heat fractured stone at an archaeological site does not automatically imply that heat-treating was practiced. What it does indicate is that a taphonomic process involving heat caused by fire and stone has taken place, with heat induced fracturing of the stone as the result.
- Size affects the temperature required to initiate heat fractures (both cracking and shattering) in silcrete suddenly exposed to heat. Thus in order to attempt descriptions of the characteristics of prehistoric fires at a site, such as their nature and frequency (Hiscock 1990:42), based on heat fractured stone, archaeologists need to be able to ascertain the original size of the stone. This may be done through a conjoin analysis. However the moisture content of the stone prior to heating, which cannot be detected archaeologically, may unfortunately distort descriptions of fires.
- There is a strong correlation between increased temperature of exposure and the resulting number of fractures. This may be able to tell us something about the characteristics of fires at a site, such as their maximum temperatures. But once again, size and moisture content of the specimen will affect this.

The experimental data presented here has provided some new and important information on the heat-induced fracturing of stone, using silcrete as the example. However it has also raised a few issues that need further exploration, such as the effects of varying size, moisture content (particularly on increasing size), and shape, variables only partially explored here. Also of interest is how these variables are related to factors such as timing and temperature. Moreover there are

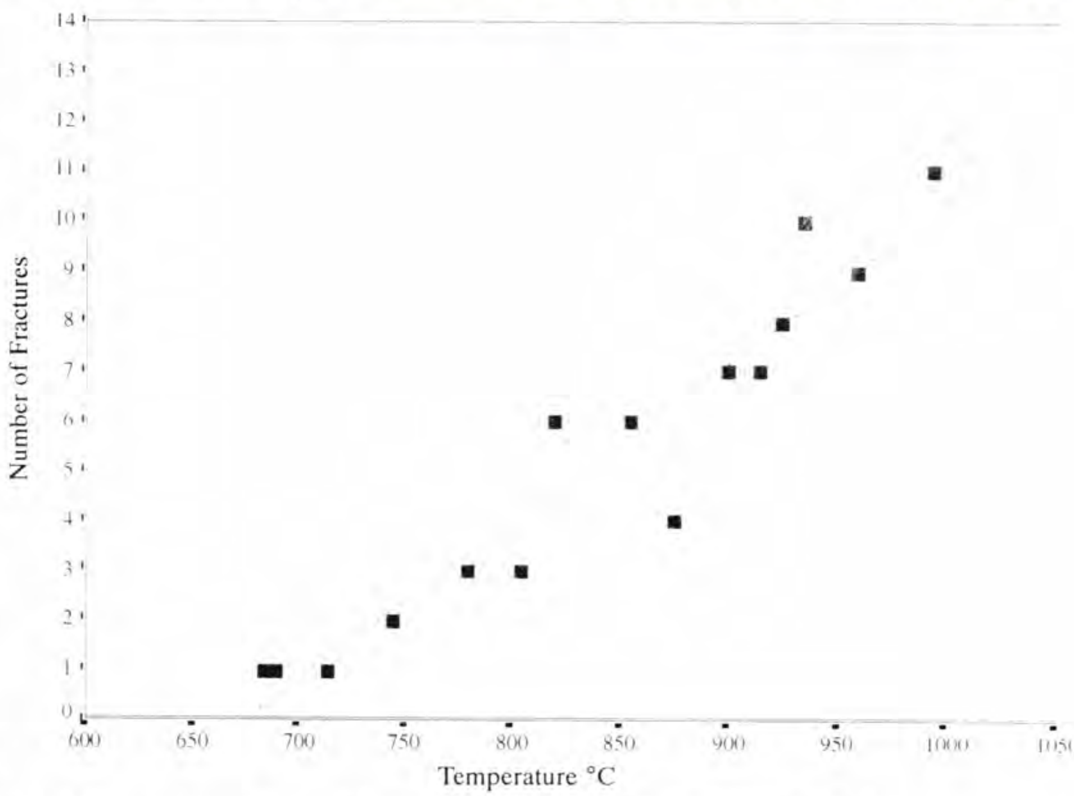


**Figure 3** Relationship between number of fractures and Temperature°C for Set 1.

numerous known yet unexplored variables that could play a role in the heat fracturing of stone, including raw material type, changes in shape, both regular and irregular, effects of using insulation, and so on. Research addressing some of these unexplored areas is currently underway.

Heat induced fracturing of stone is a process acting to transform the morphology of stone, including artefacts. It is in our best interests to research and attempt to understand the heat fracturing of stone and the mechanisms responsible. Building principles can only be of benefit to archaeologists who can then more confidently use evidence of heat fractured stone to develop inferences for explaining past human life.

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**References**

Ahler, S.A. 1983 Heat treatment of Knife River Flint. *Lithic Technology* 12(1):1-8.

Akerman, K. 1979 Heat and lithic technology in The Kimberleys, W.A. *Archaeology and Physical Anthropology in Oceania* 14:144-151.

Byrne, D. 1980 Dynamics of dispersion: The place of silcrete in the archaeological assemblages from the Lower Murchison, Western Australia. *Archaeology and Physical Anthropology in Oceania* 15:110-119.

Collins, M.B. and Fenwick, J.M. 1974 Heat treating of chert: Methods of interpretation and their application. *Plains Anthropologist* 19: 134-144.

Crabtree, D.E. and Butler, R. 1964 Notes on experiments in flint knapping1: Heat treatment of silica minerals, *Tebiwa* 7(1): 1-6.

David, B. 1990 How was this bone burnt? In S. Solomon, I. Davidson, and D. Watson (eds) *Problem Solving in Taphonomy: Archaeological and Paleontological Studies From Europe, Africa, and Oceania*, pp. 65-79. Brisbane: Anthropology Museum, University of Queensland. *Tempus* 2.

Domanski, M. and Webb, J. 1992 Effects of heat treatment on silicious rock used in prehistoric lithic technology. *Journal of Archaeological Science* 19(6):601-614.

Domanski, M. Webb, J.A. and Boland, J. 1994 Mechanical properties of stone artefact materials and the effects of heat treatment. *Archaeometry* 36(2): 177-209.

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

Flenniken, J.J. and White, J.P. 1983 Heat treatment of silicious rocks and its implications for Australian prehistory. *Australian Aboriginal Studies* 29: 22-27.

Gregg, M.L. and Grybush, R.J. 1976 Thermally altered silicious stone from prehistoric contexts: Intentional verses unintentional alteration. *American Antiquity* 41(2): 189-192.

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

Hall, J. and Hiscock, P. 1988 Platypus Rockshelter (KMA:70), southeast Queensland: Chronological changes in site use. *Queensland Archaeological Research* 5:42-62.

Hanckel, M. 1985 Hot rocks: Heat treatment at Burrill Lake and Currarong, New South Wales. *Archaeology in Oceania* 20(3):98-103.

Hassan, F.A. 1987 Re-forming archaeology: A forward to natural formation processes and the archaeological record. In D.T. Nash and M.D. Petraglia (eds) *Natural Formation Processes of the Archaeological Record*, pp.1-9. Oxford: BAR International Series 352.

Hester, T.R. 1972 Ethnographic evidence for the thermal alteration of silicious stone. *Tebiwa* 15(2):63-65.

Hiscock, P. 1982 A technological analysis of quartz assemblages from the south coast. In S. Bowdler (ed.) *Coastal Archaeology in Eastern Australia*, pp.32-45. Canberra: Department of Prehistory, Research School of Pacific Studies, Australian National University.

Hiscock, P. 1985 The need for a taphonomic perspective in stone artefact analysis. *Queensland Archaeological Research* 2: 82-95.

Hiscock, P. 1986 Technological change in the Hunter River Valley and the interpretation of late Holocene change in Australia. *Archaeology in Oceania* 21: 40-50.

Hiscock, P. 1990 A study in scarlet: Taphonomy and inorganic artifacts. In S. Solomon, I. Davidson, and D. Watson (eds) *Problem Solving in Taphonomy: Archaeological and Palaeontological Studies From Europe, Africa, and Oceania*, pp. 34-49. Brisbane: Anthropology Museum, University of Queensland. *Tempus* 2.

Hiscock, P. 1993 Bondian technology in the Hunter Valley, New South Wales. *Archaeology in Oceania* 28:64-75.

Hiscock, P. and Hall, J. 1988a Technological change at Platypus Rockshelter (KB:A70), southeast Queensland. *Queensland Archaeological Research* 5:63-89.

Hiscock, P. and Hall, J. 1988b Technological change at Bushranger's Cave (LA:A11), southeast Queensland. *Queensland Archaeological Research* 5:90-112.

Joyce, D.J. 1985 Heat treatment of alibates chalcedony. *Lithic Technology* 14(1):36-40.

Mandeville, M.D. 1973 A consideration of the thermal pretreatment of chert. *Plains Anthropologist* 18(61):177-202.

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

Mercieca, A. 1999 Burnt and Broken. Fire as a Taphonomic Agent in the Heat Fracturing of Archaeological Stone: An Experimental Approach. Unpublished BA (Hons) thesis, Australian National University, Canberra.

Nagle, E. 1914 Arrow chipping by means of fire and water. *American Anthropologist* 16(1):140.

Olausson, D.B. and 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.

Patterson, L.W. 1995 Thermal damage of chert. *Lithic Technology* 20:72-80.

Price, T.D., Chappell, S. and 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(1):37-66.

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

Purdy, B.A. and Brooks, H.K. 1971 Thermal alteration of silica minerals: An archaeological approach. *Science* 173:322-325.

Robins, R. and Stock, E.C. 1990 The burning question: A study of Molluscan remains from a midden on Morton Island. In S. Solomon, I. Davidson, and D. Watson (eds) *Problem Solving in Taphonomy: Archaeological and Palaeontological Studies From Europe, Africa, and Oceania*, pp. 80-100. Brisbane: Anthropology Museum, the University of Queensland. *Tempus* 2.

Rondeau, M.F. 1995 Thermal damage does not equal heat treatment. *Lithic Technology* 20(2):135-136.

Rowney, M. and White, J.P. 1997 Detecting heat treatment on silcrete: Experiments with methods. *Journal of Archaeological Science* 24:649-657.

Shepard, A.O. 1968 *Ceramics for the Archaeologist*, 6th ed. Washington DC: Carnegie Institution of Washington.

Tringham, R. 1978 Experimentation, ethnoarchaeology, and the leapfrogs in archaeological methodology. In R.A. Gould (ed.) *Explorations in Ethnoarchaeology*, pp.169-199. Albuquerque: University of New Mexico Press.