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Peter Bleed; Marlene Meier

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AN OBJECTIVE TEST OF THE EFFECTS OF HEAT TREATMENT OF FLAKEABLE STONE

Peter Bleed and Marlene Meier

Widely held notions about the effects of heat treatment of flakeable stone were tested by agitating matching sets of regularly shaped pieces of heated and raw chert. The tests indicate that heat treatment changes some of the variables that control flake formation although not necessarily in ways that make flintworking "easier." It appears that in order to realize an advantage to the practice, the flintknapper must call on individual skill to make technical readjustments.

In the past decade thermal pretreatment of stone by primitive flintknappers has received a great deal of attention. Archaeological and ethnohistorical research has shown that heat treat-

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Peter Bleed and Marlene Meier, Department of Anthropology, University of Nebraska, Lincoln, NE 68588

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ment of stone was common and widespread in antiquity. Understanding the effects and significance of heat treatment, however, has proved to be more difficult than observing its existence. Physical studies have suggested a number of results of heat treatment which would make the practice advantageous to flintknappers (Flenniken and Garrison 1975; Mandeville 1971; Purdy and Brooks 1971). Beyond this, though, the significance of the practice and its actual influence on the flaking properties of stone are imprecisely known. The generally held assumption that heat treatment improves the flaking quality of some stone materials rests primarily on the pioneering observations of a few skilled flintknappers (Crabtree and Butler 1964; Mandeville and Flenniken 1974; Sollberger and Hester 1973; Flenniken and Garrison 1975). Some of these observations have been anecdotal, but others have tried to systematically compare heated and unheated pieces. Such observations have been very useful because they have clarified the variables that must be controlled to obtain an accurate description of the results of heat treatment. These variables include human factors such as the knapper's skill, fatigue level, momentary judgments about placement of force, and attitude about heat treatment. Likewise, the irregularities of blank shape and "geography" have also been shown to introduce other hard-to-control factors which certainly affect flake formation in experiments involving human knappers.

This paper describes the results of an experiment undertaken to obtain an objective measure of the effects of heat treatment. In place of flaked stone blanks which would be highly irregular in shape, we used pairs of similarly shaped sawed stone tiles. To eliminate subjective human involvement in the application of force, groups of heated and raw tiles were subjected to similar agitation by being tumbled in a drum-type cement mixer. For our experiment, we used the same logical approach of earlier studies; we reasoned that differences between similar heated and unheated pieces of stone, subjected to similar forces, would be the result of the heat treatment.

METHOD

For this experiment we used chert samples from four sources in the Cannon Reservoir area of the Salt River drainage, northeast Missouri. This material was selected because Klippel (1970) has suggested that it was heat treated aboriginally. It was also hoped that our experiments would result in background information useful in the ongoing analysis of prehistoric stone tools of the Cannon Reservoir.

Using a diamond-blade lapidary saw, we cut the stone samples into 14 pairs of rectangular tiles. Initially we aimed at making each tile a squared block 1.5 by 3 by 6 cm in size. In fact, the combination of errors caused by the low tolerances of our saw, our initial low level of skill, and our attempts to optimize our raw material caused each tile to vary somewhat from our "mental template." Thus, the pairs were composed of similar but *not* identical tiles. None of the tiles had visible flaws or faults. One tile from each pair was selected for heating. The selection was random so that any irregularities in size or shape were distributed throughout the heated and unheated groups. Heating was done with an electric laboratory kiln. Tiles to be heated were placed in a room temperature sand bath. Each was surrounded by at least 3 cm of sand. The sand bath was placed in a hot kiln for 1 hour. It was then removed and allowed to cool slowly to room temperature. In order to test the effects of different temperatures, the 14 pairs were divided into two test sets. The heated half of one set of seven pairs was heated to 350° C. For the other set of seven pairs, the heated tiles were brought to 400° C.

To subject the paired sets of heated and unheated tiles to similar forces, we tumbled each set in a drum-type cement mixer for 5 minutes. The drum of the mixer had an indicated capacity of 2 cubic feet and was approximately 60 cm in basal diameter. Blades inside the drum lifted the tiles to near the top of the drum before they dropped to the bottom. The length of this fall was usually between 30 and 45 cm. In one revolution of the drum, the tiles were usually lifted and dropped twice. The drum itself revolved at approximately 50 RPMs; thus in the 5 minute test each block received some 500 blows. In addition to the falls, the tiles were also rolled against one another and abraded by the inside of the drum, which was unfortunately coated with dried cement.

At the end of each 5 minute test tiles were removed from the drum and the inside swept clean so that all flakes and other fragments could be collected. After the sweeping, a new set of seven tiles was carefully placed in the bottom of the drum and the process repeated until all four test sets had been tumbled.

After the tests were completed, we decided to investigate the effects of heat treatment by analyzing flakes rather than the flaked surfaces of the cut cores because abrasion from the cement-lined drum had crushed and rounded all of the core margins. As a first step, all of the debitage from each test was size-graded through 1/4, 1/8, and 1/16" screens. All material results from the test passed through the 1/4" screen. For our analysis, we have emphasized the Grade 4 (1/4–1/8") and Grade 5 (1/8–1/16") material. The material that passed through the 1/16" mesh contained a great deal of cement and sand grains and was of course very difficult to study. It was excluded from further consideration. The Grade 4 and 5 samples were sorted to make sure that cement and sand were removed and only flakes and flake fragments were included.

RESULTS

In order to have a structure within which to present the results of our experiments, we drew on published observations and our own knowledge of flintknappers' lore to make three predictions about the flaking properties of heated and raw stone.

Prediction 1: Heated Tiles Will Yield More Flakes than Raw Tiles.

If less force is needed to detach flakes from heat treated cores as Flenniken and Garrison (1975) and Rick (1972) have stated, we expected the incidental, light blows generated during our tests to remove more flakes from heated tiles than from the unheated control tiles. Table 1 shows the number of removals which resulted from the tests.

When compared with the control groups, heated tiles did yield a significantly larger number of flakes and flake fragments (688 versus 537, $x^2 = 18.62$, $df = 1$, $p = < .001$). The test results indicate, however, that the influence of heat treatment is not as simple as our prediction might suggest. Heating to only 350° did not have a significant influence on the number of removals. In fact the tiles heated to 350° yielded fewer total flakes and flake fragments than the matching raw tiles. Tiles heated to 400° did yield significantly more flakes than their matching raw tiles (412 versus 233, $x^2 = 49.68$, $df = 1$, $p = < .001$). The influence of heat treatment is more apparent, and perhaps most significant, among the larger flakes. Heated tiles yielded 96 Grade 4 flakes and flake fragments. The raw control tiles yielded only 61. This difference is statistically significant ($x^2 = 7.9$, $df = 1$, $p = < .01$). The 350° samples yielded more large flakes than the matching unheated control tiles, although the difference between the number of flakes detached from heated and raw tiles was significant only in the 400° test (52 versus 25, $x^2 = 9.47$, $df = 1$, $p = < .01$). The prediction is thus supported. The tests also suggest that heat treatment facilitates creation of relatively large flakes. Furthermore, heating to 400° rather than only 350° heightened the effects of pretreatment.

Prediction 2: Flakes from Heated Tiles Will Be Longer than Flakes from Raw Tiles.

If heat treatment causes flakes to "carry" farther as Mandeville and Flenniken (1974), Flenniken and Garrison (1975), and Rick (1972) have reported, we expected flakes detached from our

Table 1. Number of Flakes and Flake Fragments Resulting from Each Treatment Category.

	Grade 4(1/4"-1/8")			Grade 5(1/8"-1/16")			
	(350°C)	(400°C)	Sub-total	(350°C)	(400°C)	Sub-total	Total
Heated	44	52	96	232	360	592	688
Raw	36	25	61	268	208	476	537

heated tiles to be longer than those removed from raw tiles. The prediction was easily tested by measuring the medial axis of complete Grade 4 flakes resulting from the tests. Table 2 presents these measurements.

Student's "*t*" tests indicate that in both the 400° and 350° tests, flakes removed from heated tiles were significantly longer than removals from matching unheated control tiles. The prediction is thus supported. In all probability, though, this point requires further study since flakes that travel easily in length would expand in other directions as well. The small size of the flakes in our samples made it impractical to record complex measurements which could demonstrate this situation. The flakes in the 350° sample were markedly longer than those detached from the tiles heated to 400°.

Prediction 3: Heated Tiles Will Yield Fewer Hinge Flakes than Unheated Tiles.

Hinge fracture refers to the premature round termination of a flake at right angles to its longitudinal axis (Crabtree 1972:68). Such fractures are the bane of the flintknapper since they make it very hard to continue removal of regular flakes. If, as several published accounts (Flenniken and Garrison 1975; Collins and Fenwick 1974; Mandeville and Flenniken 1974; Purdy and Brooks 1971) suggest, heat treatment decreases the likelihood of hinge terminations, it would indeed be advantageous to the flintknapper.

Table 3 presents data on the various kinds of flakes that resulted from the tests. It shows that hinge fractures were generally quite common, accounting for about a half or more of the complete flakes in all categories. This rate of hinging seems higher than we intuitively associate with flintworking processes such as bifacial percussion thinning. It suggests that our rectangular tiles, with overall right angle margins, were especially prone to hinge fracture. Even if this is the case, heat treatment seems to have *increased* the tendency of flakes to terminate in hinges. Among the tiles heated to 400°, hinge flakes outnumbered feather terminations by more than five to one. This distribution is statistically significant ($x^2 = 15.13$, $df = 1$, $p = < .001$), and thus our results do *not* support our prediction concerning the effect of heat treatment on hinge fractures.

Since we considered only flakes and not cores, we found it impossible to differentiate between step fractures and proximal flake portions which may have been fragmented after they were detached. If proximal flake portions do reflect step fractures, our test results indicate that heating does *not* reduce their occurrence. The test group with the most proximal flake portions was the one heated to 400° (see Table 3).

DISCUSSION AND CONCLUSION

The experiments reported here have not dealt with all aspects of the heat treatment problem. They do, however, indicate that not all of the commonly held notions about the effects of heat treatment are correct. Our tests did not explore the issue in depth, but they indicate that even relatively small temperature differences (e.g., 350° versus 400°) will appreciably alter the behavior of some types of stone. Beyond that, the tests indicate (1) that less force is needed to remove flakes from heated cores, and (2) that similar forces will remove relatively longer flakes from heated cores; undoubtedly these two results are related. The relationship between heat

Table 2. Length of Complete Flakes Resulting from Each Treatment Category.

	350°C	Raw	400°C	Raw
Number of Complete Flakes	32	24	32	19
Average Flake Length	6.53mm	4.84mm	5.34mm	4.90mm

Note: ($t_s = 5.859$, $df = 55$) ($t_s = 3.819$, $df = 50$).

Table 3. Flake Types Resulting from Each Treatment Category.

	350°C	Raw	400°C	Raw
Number of Hinge Flakes	17 (53%)	13 (54%)	27 (84%)	9 (47%)
Number of Feather Flakes	15 (47%)	11 (46%)	5 (16%)	10 (53%)
Total Complete Grade 4 Flakes	32	24	32	19
Number of Proximal Flake Portions	7	2	2	1

treatment and hinge fracture is more complex. Hinge fractures are a result of several factors, including the amount and direction of force and the core shape. We interpret our results as indicating that heat treatment alone does not obviate these factors. In fact, on margins which are liable to hinge fractures (like the square edges of our tiles), heat treatment actually increases the likelihood of these undesirable results by making it relatively easy to initiate fairly large flakes. Heat treatment thus facilitates some aspects of flintworking by making it easier to detach large flakes. The practice also appears to change the relationship between factors that control flake shape and termination. Clearly though, flake shape is still determined by a constellation of factors. In order to capitalize on the beneficial effects of heat treatment, the flintknapper must still rely on expertise and craftsmanship to make the necessary technical readjustments. For archaeologists, human responses to heat treatment are more significant than the physical changes which take place in heated stones and, thus, should be the major focus of study.

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ARCHAEOMAGNETIC DATING IN THE AMERICAN SOUTHWEST

Jeffrey L. Eighmy, Robert S. Sternberg, and Robert F. Butler

Although archaeomagnetic dating seems straightforward in principle, there are practical limitations which are not generally understood. Unlike rate-dependent processes such as isotopic dating, archaeomagnetic dating requires the construction of a master record of geomagnetic secular variation. Error is inherent in such a master curve due to statistical uncertainties regarding both the magnetic directions and ages of the samples used to create the curve. The master curve itself is thus best represented as a ribbon rather than a line. Features being dated have their own error of measurement of magnetic direction, and deriving a date involves an interpretation based on the relation between the oval of confidence for the unknown and the ribbon representing the master curve. Thus a practical precision limit for archaeomagnetic dating is about ± 20 years under optimal circumstances, but the limit will generally be higher. Our pilot study revealed no major discrepancies between our work and the curves of DuBois (1975).

The possibility of using secular variation (time changes) of the geomagnetic field as an archaeological dating technique has been known to archaeologists for a number of years. A tentative interpretation of the secular record for Mesoamerica has been offered by Wolfman (1973), and DuBois (1975:137) claims to have an accurate plot of secular variation in the southwestern portion of the United States from A.D. 600 to 1500, with less accurate extensions to 300 B.C. and to the present. While the fundamental data upon which the Southwest secular variation record is based are not available, the publication of the A.D. 600 to 1500 segment provides archaeology with the first opportunity to evaluate the potential of archaeomagnetism as a dating technique in the Southwest.

With this evaluation in mind, a number of archaeomagnetic samples were collected in a pilot study of the archaeomagnetic dating technique. The research was supported by the Arizona State Museum and the Department of Geosciences, University of Arizona. Before discussing the results of this study, it may be helpful to review the process of archaeomagnetic dating. For a full discussion of "paleomagnetism" the reader is referred to Irving (1964) and McElhinny (1973). Introductions to archaeomagnetism are available in Bucha (1971), Tarling (1975), Aitken (1970), and Eighmy (1979). We will discuss the general technique of archaeomagnetic dating with particular emphasis on precision analysis in order to provide a basic introduction to the potential of archaeomagnetic dating and to its practical limitations. We will then report the results of our pilot study, addressing in particular the validity and documentation of the secular variation record of DuBois (1975).

Jeffrey L. Eighmy, Department of Anthropology, Colorado State University, Fort Collins, CO 80523
Robert S. Sternberg and Robert F. Butler, Department of Geosciences, University of Arizona, Tucson, AZ 85721

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