Thermal Alteration of Silica Minerals: An Archeological Approach

Barbara A. Purdy; H. K. Brooks

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13,870 feet (4,228 m)] is in a large room that is connected to the perimeter passage (Fig. 2) by a side passage that is 120 feet (36.6 m) long. The room measures 120 by 120 feet (36.6 by 36.6 m) and is 70 feet (21.3 m) high; it lies directly over a platform-like bench of rock that has a very precipitous downslope face. The crater wall continues to descend beyond the junction of the ice wall and floor. By projecting floor slopes from this point toward the nearby crater center, a maximum ice fill of 500 feet (152 m) was estimated.

Two rather unusual objects were found in this deep room. Lying on the floor was a badly decomposed shore bird, tentatively identified as a greater yellowlegs (*Totanus melanoleucus*), and protruding from the ceiling ice was a red woolen glove. Both objects were originally deposited on the surface and gradually worked 260 to 300 feet (79 to 91 m) downward as ice was melted from below. The glove was probably dropped less than 50 years ago by a climber, and the bird could have been a storm casualty. The frozen remains of a similar bird were found on the snow of the crater surface. The neck and head were missing from both animals, and we can offer no reasonable explanation for this.

We believe that an equilibrium exists between accumulation and melting of the crater ice. The ice above the big room probably melts at a rate of 5 to 6 feet (1.5 to 1.8 m) per year, and most of the crater ice is completely replaced every few decades. If the ice were stagnant and not actively subsiding, large ice flakes, similar to those found in the Paradise glacier caves (*12*), would develop on the cave ceiling. Flakes are large masses of ice that spall from the ceilings during periods of ice degeneration. The ice at deeper levels would also be expected to contain fewer air bubbles and be much denser if more time were available for recrystallization.

In places escaping steam has melted domelike grottoes into the ice. We call these features steam cups because of their resemblance to surface ablation features called sun cups by alpinists. The walls and ceilings of these steam cups are extremely smooth and broad, totally unlike the intricately fluted walls and ceilings of most passages (Fig. 3).

The presence of steam cups may mean that the ice mass at that point is moving downward too rapidly to allow fluted wall development or that new fumaroles have appeared. Each steam cup has a fumarole located directly beneath it. Because only a few steam cups were encountered in the mile of explored cave passage, we believe that thermal activity on Mount Rainier is not significantly increasing.

EUGENE P. KIVER
MARTIN D. MUMMA
Department of Geology,
Eastern Washington State College,
Cheney 99004

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Thermal Alteration of Silica Minerals: An Archeological Approach

Abstract. *Extensive experiments indicate that the application of heat to flint materials may have conferred an advantage to primitive man in the manufacture of chipped-stone implements. When Florida cherts are slowly heated to between 350° and 400°C and maintained at this temperature for sustained periods, a desirable change occurs in the fracture properties. This alteration takes place when the melting point of the impurities within the intercrystalline spaces is reached; thus the microcrystals of quartz are fitted closer together when materials other than quartz serve as fluxes.*

Crabtree and Butler (*1*) have suggested that thermal alteration may have played a role in facilitating the manufacture of chipped-stone implements by primitive man. Many projectile points as well as flint chipping debris from archeological sites in Florida exhibit the pinkish cast and vitreous luster indicative of thermal alteration. These objects differ markedly from materials found in outcrops. The research reported here was undertaken to test the hypothesis that the application of heat to flint materials may confer an advantage in the production of lithic tools (*2*).

A search of early historic accounts did not uncover any accurate description of the utilization of the technique of thermal alteration by aborigines (*3*). However, enough descriptions of the use of fire during some stage of stone tool manufacture were found to warrant the conclusion that primitive peoples realized that changes in siliceous materials occur when they are subjected to heat. One of the primary aims of the research reported here was to test the validity of recorded observations on the behavior of lithic materials when subjected to heating and cooling.

Most of the experiments were carried out on Florida cherts, but obsidian, English flint, Arkansas novaculite, and pure quartz were also tested. The conditions under which heating experiments were conducted were as follows: (i) the temperature was rapidly elevated, that is, the temperature was raised by 50°C increments and held approximately 1 hour at each succeeding increment until the testing temperature was reached (the length of time at the testing temperature varied); (ii) the temperatue was slowly elevated, that is, the temperature was raised by 50°C increments and held approximately 24 hours at each succeeding increment until the testing temperature was reached (the length of time at the testing temperature varied); (iii) the samples were immediately exposed to room temperature at the termination of the testing period; (iv) samples were cooled gradually in the oven at the termination of the testing period; and (v) water was allowed to drip on hot stones to test the validity of historic accounts describing "flaking" by this method.

The following techniques were used to study the heated samples and their unheated controls: differential thermal analysis, petrographic thin-section analysis, scanning electron microscopy, x-ray diffraction, tests of the rock mechanics including compressive and point tensile strength, atomic absorption spectrophotometric analysis, measurements of the porosity and surface area by the gas absorption procedure, and intuitive observations made during the production of stone tools.

The results of these experiments indicated that the color change which often occurs when cherts are heated is due only to the presence of minute amounts of iron. This color change takes place consistently between 240° and 260°C in Florida material. This temperature is not synchronous with the significant vitreous change which occurs at a higher temperature. Samples lacking significant amounts of iron [< 1100 parts per million (ppm)] did not change color. Specimens changing from N 6.5 (between light gray and medium light gray) to 5 R 7/2 (between grayish pink and pale red) contained 2500 ppm of iron. Those changing from 10 YR 6.5/2 (between very pale orange and pale yellowish brown) to 10 R 4/4 (between pale reddish brown and dark reddish brown) contained 4000 ppm of iron (*4*).

The critical temperature for Florida cherts is about 350° to 400°C. This conclusion was borne out by the fact that in this temperature range there was an increase in the amount of water lost, an explosion which occurred consistently when heat was applied too rapidly, and the development of a lustrous appearance on surfaces fractured subsequent to heating. The results of differential thermal analysis seem to indicate an endothermic trend commencing around 350°C, but this effect requires further investigation with the sensitivity of the recording galvanometer adjusted for the detection of peaks for minerals whose thermal reactions are of lesser magnitude than those normally tested.

Petrographic thin sections showed that no change occurs in the size, shape, or random orientation of the individual cryptocrystalline quartz grains. This observation is substantiated by the work of Tullis (*5*). The x-ray diffraction pattern showed identical peaks in the heated and unheated specimens, a result which bears out the results of the petrographic analysis that there is no detectable change in the crystalline properties.

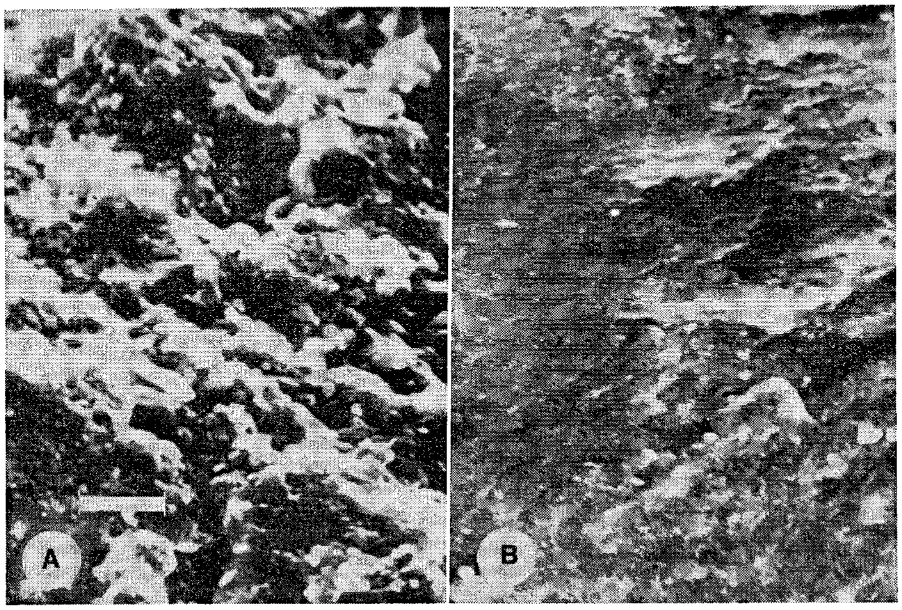

Fig. 1. Fractured surfaces of (A) unheated and (B) heated Florida chert as viewed by the scanning electron microscope (scale = 63,600 Å).

The scanning electron microscope dramatically illustrates the change which occurs when cherts are heated (Fig. 1). The fractured surface of unheated maerials shows the individual microcrystals resembling bread crumbs, whereas the fractured surface of the heated sample is extremely smooth. Fractures pass through the cryptocrystals in the heated sample, rather than around the cryptocrystals as in the heated sample.

The individual mineral grains of microcrystalline quartz are held more firmly together in the heated specimens than in the unheated specimens. Minute amounts of impurities (or compounds of the elements making up the impurities) in the intercrystalline spaces of the chert are probably acting as fluxes (substances promoting fusion) to fuse a thin surface film of the cryptocrystals. This fusion occurs when the melting point (eutectic development) of the impurities is reached, which explains why alteration occurs at temperatures of 350° to 400°C; temperatures of 1400° to 1700°C (> 3000°F) would be needed to transform microcrystalline quartz structures to a noncrystalline, amorphous form. Binding of the microcrystals results in a more homogeneous material with the ability to fracture like glass rather than like a rock aggregate. Flakes tend to feather

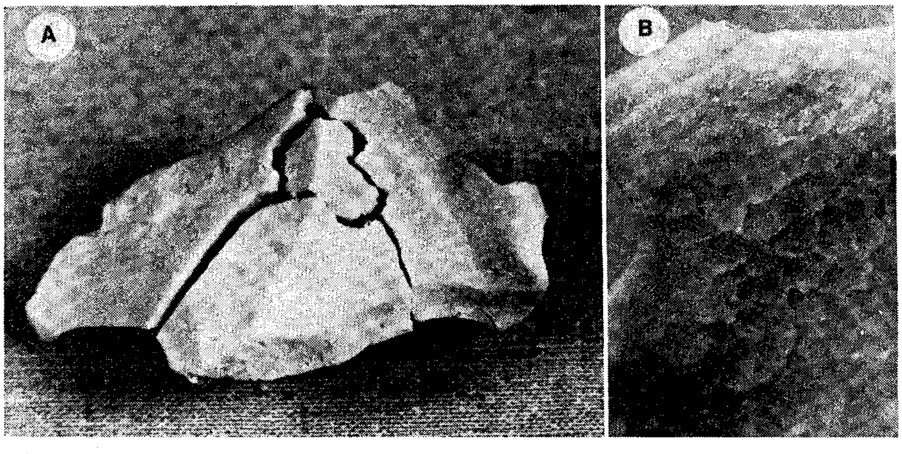

Fig. 2. (A) Results of experiment conducted to test the possibility of "flaking" hot stones by dripping cold water on them; (B) a magnified area illustrating the crazing which occurred.

out rather than to step off after alteration has taken place.

Tests of compressive strength demonstrated that three types of unheated samples withstood forces ranging from 3000 to 3600 atm, whereas heated samples of the same material that had been removed immediately from the oven at the termination of the testing period withstood forces ranging from 1700 to 2200 atm, representing a 40 percent reduction of strength. However, when samples were allowed to cool gradually in the oven at the termination of the testing period, heated samples exhibited an increase in strength of 25 to 40 percent over that of the unheated controls.

Tests of point tensile strength (*6*) demonstrated that unheated Florida cherts withstood forces of 180 atm (this is the arithmetic mean of several tests), whereas heated samples (350°C) of the same material withstood a mean force of 100 atm; thus there is a reduction of 45 percent in the force needed to break the material. Additional loss of strength (as much as 25 percent) occurred when materials were removed immediately from the hot oven at the termination of the testing period. There was also an increased loss of strength with increased temperatures under point tensile load. Although there was no apparent increase in flaking ease, quite often attempts to chip flint materials that had been heated to between 500° and 600°C or had been heated to between 350° and 400°C and removed immediately from the hot oven resulted in a lateral snap due to end shock. This fracture did not occur at the point of impact. Flint knappers are familiar with this type of failure since it occurs when a substantial blow is imparted to a rock whose mass is not adequately supported to absorb the shock. With these heated materials, however, failure occurred when only slight pressure or percussion was applied. Such failure must be due to residual stresses within the rock.

Fig. 3. Specimens from the University of Florida collections showing dull areas not flaked subsequent to thermal alteration surrounded by extreme vitreousness in areas that have been flaked after alteration.

If a comparison is made between the results obtained from tests of compressive strength with those for point tensile strength, a discrepancy seems to exist: under compressive strength when samples are allowed to cool in the oven, they resist failure longer than unheated controls, but the results of tests of point tensile strength revealed a significant reduction in the time and load necessary to cause failure in heated samples, regardless of whether they were removed from the oven while hot or allowed to cool in the oven. This seeming paradox is easily explained. The binding of the microcrystals which occurs when the rock is heated adds compressive strength through cohesion. The increase in homogeneity which increases strength under compression is the very factor which decreases point tensile strength: (i) the individual microcrystals are bound more firmly together; therefore (ii) when the flaw is introduced (*7*) which is preliminary to and necessary for fracture to occur, (iii) failure takes place more readily because the specimen responds like glass rather than like a rock aggregate.

Determination of the porosity and specific surface area by the gas absorption technique revealed that there is approximately a 60 percent reduction in the granular surface area of heated chert. This effect is due to the reduction of the intergranular pore radii; that is, the porosity was decreased because of the fusion or intergrowth of the contact surfaces of the microcrystals.

The changes that have taken place in the stone produce a structural but not a mineralogical alteration. The change is gradual rather than abrupt but if the sample is heated to between 350° and 400°C and kept at this temperature for sustained periods, the sample develops the vitreous luster which appears to be the most significant characteristic of thermally altered Florida cherts. Chert is composed of microcrystals which constitute the mineral phase known as chalcedony. Mineralogically, chalcedony is waxy or greasy in luster but individual faces of this mineral are normally not seen because the crystals are anhedral (no definite shape or orientation), usually subequidimensional, and microscopic. Therefore, when fracture occurs, especially if the rock is coarse-grained, the fractured surface is dull as a result of refraction and poor reflection. After heating, the fractured surface is vitreous because of the greater reflectance of light which occurs when the fracture passes through successive microcrystals and intercrystalline spaces, revealing the true luster of quartz. After thermal alteration crystal boundaries no longer interfere with the removal of flakes.

This research also refutes the oft-quoted description of the mythical "flaking" of stone caused by dripping water. Attempts to "chip" by dripping cold water on hot chert resulted in a crazing of the material. Subsequent attempts to flake by pressure and percussion caused the material to crumble, and no predictable fracture was possible (Fig. 2).

The following recommendations are made to aid archeologists in determining if chipped-stone remains have been intentionally thermally altered. (i) If an investigator is familiar with outcrop materials in his area, it is a simple task to compare outcrop material with chipping debris to determine if differences exist. (ii) An archeologist could easily and inexpensively conduct heating experiments with outcrop materials to ascertain whether changes occur resulting in specimens whose appearance resembles artifactual remains. (iii) Color change, at least for Florida cherts, takes place at a lower temperature than the significant alteration which results in greater chipping ease. However, if it is noted that color change is accompanied by a vitreous luster on flaking detritus, the color change might be used as a criterion in establishing that thermal alteration was practiced. (iv) The foregoing statement gains validity if the vitreous fractured surface possesses a bulb of percussion indicating that impact has occurred. This observation eliminates objections which may be raised suggesting that thermal alteration may have taken place accidentally, for example, from forest fires or at hearths. Fractures resulting from too rapid expansion and contraction occur explosively and with the conchoidal fracture typical of flint materials but do not have a bulb of percussion. (v) Finally, in examining a representative sample of flaking debris or artifacts that are suspected of being altered, an investigator should find a number of specimens which exhibit a relict dull area surrounded by areas of extreme vitreousness. This situation suggests that the dull area has not been flaked subsequent to heating whereas the vitreous areas have been. Soil conditions would not produce this type of differential preservation (Fig. 3).

Evidence indicates that primitive man altered lithic raw materials by slowly heating them to critical temperatures for sustained periods. He was probably well aware of the advantages this practice conferred in the manufacture of chipped stone implements.

BARBARA A. PURDY
Florida State Museum,
Gainesville 32601

H. K. BROOKS
Department of Geology, University of
Florida, Gainesville 32601

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Channelization: A Case Study

Abstract. *Channelization of the Blackwater River in Johnson County, Missouri, 60 years ago nearly doubled the gradient, which caused an increase in the rate of erosion for the river and its tributaries. Since the present channel is much wider and deeper than it was when newly dredged, there have been bridge repairs and loss of farmland. Downstream reduction in channel capacity due to termination of dredging has caused channel sedimentation and increased flooding.*

Channelization means straightening of a stream or the dredging of a new channel to which the stream is diverted. The purpose is to minimize local flooding by shortening the distance traveled and thereby moving the floodwaters downstream more rapidly. This technique has been practiced for many years by private drainage districts, the Army Corps of Engineers, and, more recently, the Soil Conservation Service under Public Law 566 (*1*). Recently several articles concerning channelization have appeared in newspapers and magazines (*2*, *3*). The detrimental effects on game and fish populations and on landscape esthetics have been widely described, but there has been a paucity of data about changes in stream channel geometry. This report documents the increase in erosion caused by channelizing a stream and thereby increasing its gradient.

The headwaters of the Blackwater River are in northwest Johnson County, Missouri, about 65 km east of Kansas City. The river flows east to join the Missouri River just west of Boonville, Missouri. A local drainage district was formed in 1909, and in 1910 a new channel was dredged for the lowland portion of the Blackwater River eastward nearly to the county line.

The pre-1910 river in Johnson County had an average of 1.8 meanders per kilometer, with a meander radius ranging from 60 to 140 m. This former channel is now blocked off, silted up, full of vegetation, and used as a dump wherever the original bridge remains in use. These bridges over the former channel are from 15 to 30 m wide, the majority being of the smaller width. The length of the old channel, from the beginning of the new ditch to the county line, was 53.6 km, and the gradient was 1.67 m per kilometer.

County Circuit Court records state the dimensions of the new Blackwater ditch, those of the dredged tributaries, and the length of new bridges to cross the dredged channels (*4*). The new Blackwater channel was 9 m wide at top, 1 m at bottom, and 3.8 m deep, giving a cross-sectional area of 38 m^2.

Length and elevation measurements for the former and present channels were made on topographic maps. Channel widths were taken by taping across bridges on straight portions of the present river. Channel depth was obtained by lowering a lead line, marked in meter increments, from the bridge. A hand level was used to sight from one bank to the other, and the height of the intersection of the line of sight with the lead line was noted. At the same time, bottom elevation was obtained by measuring the length from the bridge floor to the stream bed and subtracting this distance from the bridge elevation given on the topographic map. The measurements are given in Table 1 and in the stream profile (Fig. 1).

The present Blackwater River is 29 km long from beginning of channelization to the county line and has a gradient of 3.1 m per kilometer. The dredging shortened this portion of the river by 24.6 km and nearly doubled the gradient. The present channel has increased from a cross-sectional area of 38 m^2 when newly dredged to a size now ranging from 160 to 484 m^2. The maximum figure represents an area increase of 1173 percent in 60 years. For a comparison of the present channel width with the width of the old abandoned channel, measurements of the bridges that cross both are useful. At

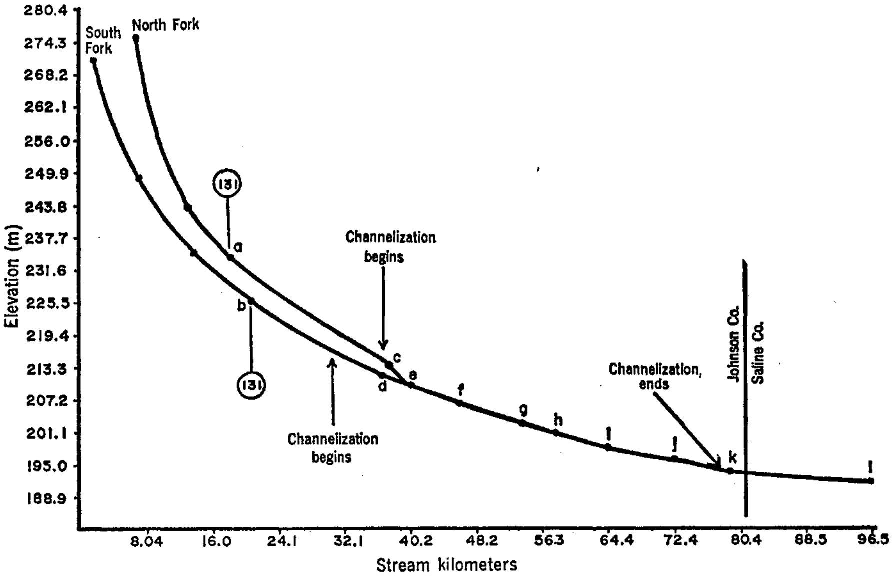

Fig. 1. Stream profile of the Blackwater River in Johnson County and the western part of Saline County. Location of the measured bridges is designated by letters **a** through **l**. Measurements were made in 1970.