

Heat-Treating Experiments With Onondaga Chert: Preliminary Results*

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Heat-treatment in lithic technology refers to the controlled heating of quartz-rich, brittle, elastic lithic materials in order to reduce fracture toughness and improve knapping qualities. Successful heat-treatment reduces the point-tensile strength of many varieties of micro-crystalline quartz, including chert, without perceptibly altering any of the other properties with regard to fracture. This reduction in fracture toughness has tangible benefits to the knapper in terms of the relative ease with which fracture can be accomplished and controlled.

Heat-treated materials require the application of less force to produce flakes. Longer and, frequently, thinner flakes can be detached from heat-treated stone than can be removed with equivalent force from unheat-treated stone (Crabtree and Butler 1964; Flenniken and Garrison 1975; Mandeville and Flenniken 1974; Rick 1978). The increased ease of flake fracture significantly enhances the knapper's control over the material. Failure rates in the production of chipped stone tools may be diminished. Greater latitude and flexibility may be possible in both the choice of retouching techniques, and in the variety of functional products that may be produced from a given lithic unit.

Heat-treatment is not, however, a necessary technological step in the stone tool manufacturing process. Many of the better quality lithic materials can be successfully knapped without thermal alteration. Heat-treatment is therefore an optional technological process in the manufacture of stone tools. It is a process which involves definite labor and time costs, and often certain risks, as well as variable potential benefits.

It is thus of interest to archaeologists to be able to recognize the use and effects of heat-treatment. When archaeologists are investigating the use of lithic materials for which heat-treatment is possible, technologically useful and analytically identifiable, the recognition of heat-treatment may allow us to ask interesting questions concerning prehistoric technological decision-making processes. Such decisions may have involved a considered balance of costs and benefits of heat-treatment with respect to various kinds and grades of raw material, with respect to the products (and by-products) of manufacture, and with respect to circumstances of raw material availability (distribution across the landscape), or logistical considerations (bulk- or weight-carrying capacities, reuse capabilities, etc.) (eg., Goodyear 1979).

The primary purpose of this investigation is to determine whether heat-treating procedures can appreciably improve the flaking qualities of Onondaga chert, and whether heat-treating effects can be recognized in Onondaga chert. If these questions can be answered affirmatively, we are in the position to determine whether the aboriginal tool-makers of western New York employed this technological process, for what purposes, and under what conditions it was viewed as beneficial and worthwhile.

It should be noted at the outset that there is no clearcut archaeological or ethnographic evidence that deliberate thermal alteration was prehistorically employed with Onondaga chert. This study is therefore exploratory in nature. The only published consideration of heat-treating effects on this chert type (Lavin 1983) was concerned only with documenting what color changes might be produced in New York cherts by heat-treating. Lavin concluded that heat-treating could produce some subtle color changes in Onondaga chert, but that the resulting colors were still within the natural range of variation for this quite variable material. Significantly, Lavin does not seem to have examined the appearance of the chert on fresh fracture surfaces produced after heat-treatment, which is the variable of interest to archaeologists interested in recognizing the use of heat-treatment. Nor did she examine the properties of interest to the knapper: changes in texture or tensile strength which would signal potentially improved flaking qualities.

While heat-treatment has not been documented for Onondaga chert, it is well documented for many regions throughout North America (eg., Collins and Fenwick 1974; Crabtree and Butler 1964; Mandeville 1973; Purdy 1974; Shippee 1963; Struever 1973), in Australia (Akerman 1979; Flenniken and White 1983), Siberia (Flenniken and White 1983; Flenniken, personal communication, 1984), and Europe (Bordes 1969; Collins 1973; Price, et al. 1982; Robins, et al. 1978). Closer to the western New York area, heat-treatment has been fairly convincingly implicated for Palaeoindian tools and debris of Fossil Hill chert in Ontario (Pavlish and Sheppard 1983), and well documented for jaspers in Pennsylvania (Schindler, et al. 1982; Hatch and Miller 1985). Given the apparently common prehistoric knowledge of the process and its geographically and temporally widespread usage, it would be surprising if heat-treatment were not a part of the technological repertoire of Onondaga users, if it imparted any advantage to the material.

BACKGROUND LITERATURE

Beyond some general and often ambiguous ethnographic descriptions of the heat-treatment process (Hester 1972; Holmes 1919; Pond 1930), the process of heat-treatment was first experimentally explored and documented by Don Crabtree (Crabtree and Butler 1964). Since that time, a large body of literature has developed concerning the technologically useful consequences of heat-treatment, hypotheses concerning the physical/chemical processes by which the observed thermal alterations take place, techniques for its identification, and the archaeological documentation that prehistoric peoples were aware of the process and often employed it as part of the stone tool manufacturing process.

Physical Effects and Processes

The utility of thermal alteration of siliceous to stone tool-makers appears to result primarily in the reduction of point tensile strength of the stone as a consequence of heat-treatment. Heat-treatment has been shown to result in a point-tensile strength reduction of 30% to 70%, depending on material and heat-treating temperature curves (Purdy 1974; Purdy and Brooks 1971; Rick 1978; Schindler, et al 1982). Various investigators have used scanning electron microscopy to compare the fracture surfaces of heated and unheated cherts (Draper and Flenniken 1984; Flenniken and White 1983; Johnson 1985; Olausson and Larson 1982; Purdy 1974; Purdy and Brooks 1971; Robins, et al 1978). In comparing fracture surfaces produced before and after heat-treatment, they find that heat-treated cherts fracture to form much smoother surfaces. In unheat-treated cherts, fracture fronts appear to pass between the quartz microcrystals, breaking the relatively weak bonds holding the crystals together. At the high magnification used in SEM, these surfaces appear topographically rough. In heat-treated cherts, however, the fracture appears to pass through many of the microcrystals, leaving a much smoother fracture surface. The smoother surface reflects light more evenly and produces an increased surface luster or "greasy" texture that is macroscopically visible and has served as an indication of thermal alteration to many investigators (Bordes 1969; Crabtree and Butler 1964; Rick 1978).

The physical/chemical changes that take place during heat-treatment are poorly understood. Purdy and Brooks (1971) have suggested that impurities (particularly iron compounds) within the microcrystalline quartz latticework may reach a eutectic melting point. They suggest that "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 on the cryptocrystals. This fusion occurs when the melting point (eutectic development) of the impurities is reached... Binding of the microcrystals results in a more homogeneous material with the ability to fracture like glass rather than like a rock aggregate" (Purdy and Brooks 1971).

Flenniken and Garrison (1975) have countered with the observation that the Purdy-Brooks hypothesis depends upon particular mineral impurities which are not universally present in chert or other materials which respond positively to heat-treatment. They suggested that interstitial moisture present in the crystalline structure would expand forcibly as a gas with heating, and water vapor would escape by micro-fracturing the crystalline latticework. Several observers have noted that heat-treating results in small but measurable weight loss probably due to the loss of water (Mandeville 1973; Purdy and Brooks 1971).

More recently, Schindler, et al. (1983) have offered another mechanism whereby heat-treatment reduces the tensile strength of Bald Mountain jasper, although they do not claim that it as a mechanism generalizable to a larger class of materials. In heat-treating the central Pennsylvanian jasper to approximately 275 degrees C., Schindler, et al. noted that the jasper undergoes a distinctive color change from yellow to deep red. Concurrent with the color shift, they observed that there is a 50% reduction in point-tensile strength. In determining that the color transformation was the result of a recrystallization of goethite to hematite, a denser material, they noted that the volume reduction of the iron compounds left small "channels" permeating the reddened stone. They reasoned that these small voids were the cause of the reduction in tensile strength, and hence the thermal alteration mechanism for Bald Mountain jasper.

The last hypothesis, aside from positing a unique mechanism for a unique material, suffers from a flawed research design. All of the jasper samples heat-treated and tested were very small (1 cm) cubes (Schindler, et al. 1983:528). It is typical for heat-treated jaspers to undergo a dramatic color change only near the heated surfaces; reddening seldom penetrates more than a few millimeters into the mass of the rock. Although unreddened, heat-treated jasper within larger stone masses is nonetheless thermally altered as clearly demonstrated by reduced fracture toughness and increased luster of fracture surfaces. The direct equation of color change with the alteration of fracture characteristics forced Schindler, et al. (1983:537) to advance ludicrous technological interpretations, such that large cores or bifaces would have to be heat-treated more than once during the reduction process.

In most cherts (and other varieties of microcrystalline quartz and some quartzites), successful heat-treatment usually involves raising the temperature of the stone to approximately 275 degrees C., and maintaining that temperature for a period of several hours (Flenniken and White 1983; Mandeville and Flenniken 1974). The critical temperature at which thermal alteration occurs and the length of time the material must remain at that temperature is apparently quite variable with differing kinds of materials. Flenniken and Garrison (1975) have found that Arkansas novaculites require very high temperature curves, with thermal alteration only successfully occurring with sustained temperatures of 450-500 degrees C. Purdy and Brooks (1971) reported that color changes consistently took place in Florida chert heated to between 240-260 degrees C. when iron was present in concentrations of at least 1,100 parts per million. Critical temperatures for effecting textural changes were 350-400 degrees C. Rick (1978:60) reported that Burlington chert underwent color changes (apparent iron oxidation) at approximately 230-290 degrees C., but that textural changes were not apparent at less than 290-370 degrees C. Personal experimentation has indicated that Burlington cherts may be successfully heat-treated at much lower temperatures. Sustained temperatures of 275 degrees C. appears to be sufficient, although higher temperatures will produce higher, more vitreous lusters. My experiences with heat-treatment suggest that generally more vitreous materials, and darker colored cherts and flints require less heat than lighter colored cherts, and, in fact, many high quality materials can not survive the high temperature curves suggested in some of the literature. This observation is concordant with the experiences of other knappers experimenting with heat-treatment (Crabtree and Butler 1964; Flenniken, personal communication, 1984; Rick 1978:61).

The upper temperature limit of successful heat-treating is definitely fixed at 573 degrees C. (at one atmosphere of pressure), the low quartz/high quartz inversion point (Hurlbut and Klein 1977:411-412). At 573 degrees C., at one atmosphere of pressure, quartz undergoes an instantaneous and reversible transformation of crystal structure. "This displacive transformation

from low to high quartz involves only minor atomic adjustments without breaking of Si-O bonds. Upon cooling high quartz, through the inversion point at 573 [degrees]C, Dauphine twinning may be produced" (Hurlbut and Klein 1977:415). Although Hurlbut and Klein (1977:411) report that the inversion may be repeated "over and over again without physical disintegration of the crystal", this temperature does represent the apparent threshold beyond which microcrystalline quartz aggregates can not cross without disintegrative effects. Whether because of the reversible alteration of individual crystal symmetry or the morphological transformation to Dauphine twinned low quartz, the effect is that a rock unit of chert no longer has any structural integrity, and tends to become friable and sometimes chalky and will crumble rather than break conchoidally with any applied force. Several investigators have noted this decrepitation (Mandeville 1973; Mandeville and Flenniken 1974; Purdy 1974, 1975; Schindler, et al 1982), although apparently some have not been aware of the crystallographic basis for it.

The controlled nature of successful heat-treatment becomes apparent with the consideration of temperature change rates. Rapid heating results in explosive fractures as excess moisture trapped in voids, fissures, pockets, and in the interstices between microcrystals vaporizes. Differential expansion of the brittle material results in characteristic "potlid" fractures. Overly rapid cooling results in reticulated fractures or "crazing". Rapid cooling and uneven mass shrinkage causes distinctive "reticulated" fractures which occur abruptly across the thickness of a chert blank and often leave a rippling surface across the fracture oriented to the broader dimensions of stone (Purdy 1975).

Conceptually and observationally, the distinction between heat-treatment and fortuitous burning is essential. Poorly controlled heat-treatment attempts can produce all of the fractures discussed above. Nonetheless, the abundant burnt and pot-lidded chert debitage and artifacts recovered from most archaeological sites pertains to fortuitous spatial congruences of debitage and fires burning for other purposes, congruences which are not necessarily the result of synchronous activities or deposition. Post-depositional fires, whether humanly caused or the result of natural processes, may alter cherts, although the results are most likely to result in characteristic fractures of thermal shock, 'smoked' surfaces or structural deterioration to blue-black color and chalky textures. The distinctive textures of controlled thermal alteration for technological purposes occur on surfaces flaked after heat-treatment. This is not to say that heat-treating attempts will always be successful, as the following experiments with Onondaga chert will show. Nonetheless, once the appropriate heat-treating conditions and variables for particular materials are learned and understood, it would be likely that the frequency of unsuccessful heat-treating attempts would be low. If the heat-treatment of chert were a highly risky undertaking, with the likely loss of time, labor and scarce raw materials, it would be unlikely that it would be pursued as a maximizing strategy.

HEAT-TREATING EXPERIMENTS WITH ONONDAGA CHERT

Samples of flakable Onondaga chert were collected for this exercise from an exposure of cherty Onondaga Limestone exposed by an abandoned railroad cut in the City of Buffalo. The exposure consists of a vertical cut several hundred meters long and several meters wide through bedrock exposing from three to six meters of bedrock stratigraphy with talus covering the lowest 1-2 meters. At this locality, the formation consists of finely bedded limestone lenses of variable thickness and texture, interbedded with discontinuous chert beds and layers of chert nodules. The exposed chert varies considerable in color, texture, quality and integrity. Much of the exposed chert is firmly embedded in the limestone matrix. Most of the looser chert is degraded by weathering and jointed or fractured by geologic forces, roadcut blasting and exposure to frost and other weathering forces. Nonetheless, an appreciable amount of suitable quality chert can be extracted from both weathered primary bedding sources and from secondary talus deposits. All collected materials were extensively tested for quality prior to removal from the outcrop locality. Cores suitable for transport of up to approximately 1130 grams in weight were obtained, although the median mass of selected samples was less than half that weight.

The chert samples chosen for heat-treatment experimentation consisted of 24 tabular chert blocks, large flakes, and roughly preformed bifacial cores. Each piece was flaked to provide one or more large flakes for control samples to compare with the heat-treated cores, and each sample and control flake was appropriately labelled. The median thickness for heated samples was 36.5 mm, while the entire sample ranged from 25 to 60 mm in maximum thickness.

Two fairly distinct varieties of Onondaga chert were collected from the outcrop. One variety is a very dark gray to black chert (Munsell color approximated by 2.5Y 3/0 to 3.5/0) with somewhat lighter gray to bluish gray mottles (ca. 2.5Y 4/0 to 5/0). This chert is fairly vitreous and homogeneous in texture and flakes with an excellent conchoidal fracture. The second variety obtained from the same outcrop is a much lighter gray (predominantly about 2.5Y 4.5/0) with both dark gray and black mottles and many very light gray mottles (to about 2.5Y 7/0). The lighter gray chert has a drab or matte surface texture. In general, it flakes with a good conchoidal fracture, although it is somewhat more splintery than the dark material, especially for smaller, thinner flakes. Both materials were judged to be of good to excellent quality when tested by percussion flaking at the source locality.

The first heat-treating attempt involved fifteen chert samples, seven of which were the darker chert, eight of the lighter gray chert. The chert samples were allowed to dry indoors for several days to ensure that excessive moisture would not be contained in surficial pores or fissures of the material. The rocks were placed in metal pans completely surrounded and covered by dry beach sand and placed in an electric kitchen oven. Samples of Burlington chert were similarly treated to provide a familiar comparison sample of known heat-treating characteristics.

Previous heat-treating experience had shown that dark-colored, vitreous cherts were unlikely to survive the heat-treating temperature schedule I have generally employed with the light-colored Burlington cherts. Previous samples of Onondaga chert heated along with other cherts had suffered extensive 'pot-lid' fracturing and general deterioration, although occasionally small Onondaga samples had heat-treated to good effect. With this in mind, I followed a modified heating schedule which was more gradual in temperature increase and peaked at temperatures appreciably lower than the 525 degrees F. (275 degrees C.) I have generally employed. Table 1 illustrates the heating schedule followed for both the first and second heat-treating attempts.

The results of the first heat-treating attempt were totally unanticipated. No apparent damage occurred to any of the chert blanks during the heating process. Nonetheless, upon testing the material by percussion flaking after cooling, it was evident that all of the darker colored chert samples had undergone drastic physical deterioration. The darker rocks no longer broke with a conchoidal fracture. Instead, 'flaked' surfaces broke with a crumbly fracture, producing a hackly surface texture on both the ventral 'flake' surface and on the scar. All structural integrity was gone, and the formerly excellent quality chert was no longer suitable for any technological purposes.

The lighter gray chert specimens, on the other hand, evinced no apparent change as a consequence of heating. Each heated blank was extensively flaked by percussion and ventral flake surfaces and flake scars were compared to the appropriate control specimens. No changes were evident in either appearance, texture or flaking characteristics. The Burlington chert was similarly unaffected by this temperature curve.

A second heat-treating was conducted to investigate the effects of a somewhat higher temperature curve on the lighter gray variety of Onondaga chert. Nine pieces, not previously heated, were heated to a maximum temperature of c. 275 degrees C. (see Table 1) employing the same methods as used in the first heating attempt. The Burlington chert samples were again included for comparison. Also included were chert specimens of unknown geological source obtained from near the town of Harvester in southwestern Missouri. This yellow chert has a somewhat coarse, matte texture similar to that of the lighter gray Onondaga.

The second heat-treating successfully altered both the Burlington and 'Harvester' cherts. These samples underwent significant color changes from heating and the flake scar surfaces produced after heating exhibited textures much glossier than before heating. The flaking characteristics of these two quite distinct cherts were tangibly improved by the process.

The Onondaga samples exhibited no clearcut changes or improvements from the heating. Two blanks cracked during the cool-down phase several hours after the oven had been turned off. These fractures produced fine hairline cracks cross-cutting but not separating the material. The other seven pieces were extensively tested by percussion flaking. For the most part, there was no recognizable change nor appreciable improvement in flake surface textures or flaking characteristics. This was further evaluated by bifacially reducing three pieces while alternately reducing unheated control specimens of comparable appearance and quality. In two cases, the heated light gray Onondaga was indistinguishable from unheated control samples. These units were workable but rather tough. Especially noticeable during pressure flaking, thin flakes tended to be somewhat splintery and susceptible to step fracturing. In one case, however, the material may have been detrimentally affected. Sample #20 broke into several pieces with the application of a hard blow aimed deeply to produce dramatic thinning. The nature of the fracture is very suggestive of thermal stress. However, it is possible that the piece was simply flawed to begin with.

Summary

In summary, two heat-treating attempts failed to thermally alter samples of Onondaga chert in technologically satisfactory ways. These experiments employed two temperature curves and involved two distinct grades of Onondaga chert obtained from a primary local source. The high-quality, very dark gray to black Onondaga specimens were completely degraded by a gradual heating to no more than 400 degrees F. The coarser, light gray colored Onondaga chert, on the other hand, did not appear to be altered even with a temperature curve attaining 275 degrees C. (525 degrees F.). Six of the nine specimens heated at the second, hotter temperature schedule were visually and technologically indistinguishable from unheated control specimens. Three of the nine were detrimentally affected by the heating. Two blanks developed hairline cracks during the protracted cooling phase. A third broke during knapping in a manner at least suggestive of thermal stress-induced weakness.

An SEM examination of a single matched pair of flakes, one heated and the other unheated, appears to confirm that no clearcut changes in fracture surface topography have taken place. The cursory SEM examination did suggest however that the chert is quite heterogeneous in its fracture surface texture at the scale of magnifications employed by SEM (Figures 1 through 4). Since internal variation is high, textural changes induced by heat-treatment would have to be quite distinct to be consistently detected by such methods.

CONCLUSIONS

The results of this limited experiment are not without ambiguity, and the experiments can not be considered as critical tests of propositions concerning the possibility, utility and detectability of thermal alteration to Onondaga chert. More experiments employing a wider range of Onondaga chert varieties and a wider range of temperature curves will be necessary before it can be concluded whether Onondaga chert can or can not be successfully and usefully heat-treated. Such experimental work must logically precede investigations of archaeological materials in order that the archaeological record can be sampled in an informed and efficient manner. Nonetheless, the limited results of this preliminary investigation have been illuminating, and some general conclusions can be drawn.

1) Higher quality black cherts of the Onondaga series are unlikely to have been heat-treated prehistorically. The qualities of the material may be of sufficient excellence that heat-treating would have been of negligible value, even if it is possible. The deterioration noted in

this experiment further suggests that even if it is possible to heat-treat the black chert, it would have been a relatively high risk-low return investment. It would have demanded considerable control over all relevant variables, with temperature ranges held within tight tolerance levels. In such cases, it was probably advisable to heed the admonition of the Quaker Oats man in the TV commercials of yore: "When you've got a good thing, don't mess with it."

2) Coarser textured (though generally homogeneous) light-colored Onondaga cherts were not successfully heat-treated at the temperature ranges experimentally explored. The possibility that this grade of chert can be successfully altered can not be ruled out, since the lighter material may simply require higher temperatures than have been attempted thus far. Nonetheless, the breakage rate experienced in this experiment, if representative, suggests that heat-treatment may be a relatively high risk investment. It may be that thinner blanks would obviate the kinds of breakage that occurred to two of the lithic units during the cooling period. Since the experimental sample is so small and cherts frequently have many hidden flaws, the relatively high ratio of failure experienced here may not be typical. However, it may have been simply easier and more economical to invest greater efforts in selectivity of and at source locations to retrieve only the higher quality materials if very high qualities were required for projected technological needs. Further, since the lighter material is not unworkable by any means, increased investment in tool production activities and higher tool manufacturing failure rates may have been adequately balanced by lesser investments in procurement selectivity or in heat-treatment.

The decision of whether or not to heat-treat chert undoubtedly involved the balanced equation of many variables. In general, such decisions involve the interplay of anticipated tool needs in terms of technical difficulty of tool manufacture, the limits of acceptable tolerances in production results, rejuvenation and recycling capacities. These factors must be weighed against the qualities, quantities and spatial distributions of available raw materials, the technological skill of tool-makers, time and labor costs involved in heat-treating, time and labor scheduling, and levels of risk involved in heat-treating. In the case of Onondaga chert (for the moment presuming that some grades can be usefully heat-treated), an additional factor would have been knowledge of the heat-treating potential and requirements of the numerous grades and varieties of the material.

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TABLE 1. EXPERIMENTAL HEAT-TREATING SCHEDULES.

	Experiment 1	Experiment 2
Hour	Temperature °F	Temperature °F
1	125	125
2	225	250
3	300	400
4	400	500
5	400	500
6	400	525
7	400	525
8	400	525
9	*	*
10	*	*
11	*	*
12	*	*
13	(200)	*
14	*	(200)

Asterisks () denote that the oven was turned off and allowed to cool naturally with the door closed. Temperatures for hours 13 and 14 (in parentheses) are estimated residual temperatures for very hot sand and chert after the oven had cooled.*

LIST OF FIGURES:

(The following images were not available when this pdf document was created.)

Figure 1. Scanning Electron Micrograph of an Unheated (Control) Sample of Light Gray Onondaga Chert at 500 Diameters Magnification. Bar Scale is 10 Microns. Rhombohedral Crystals are probably Calcite.

Figure 2. Scanning Electron Micrograph of a Heated Sample of Light Gray Onondaga Chert at 500 Diameters Magnification. Bar Scale is 100 Microns.

Figure 3. Scanning Electron Micrograph of Unheated (Control) Sample of Light Gray Onondaga at 2,000 Diameters. This is the same flake as Figure 1. Bar Scale is 10 Microns. Rhombohedral crystals are calcite.

Figure 4. Scanning Electron Micrograph of Heated Sample of Light Gray Onondaga Chert at 2000 Diameters Magnification. This is the same flake as in Figure 2. Bar Scale is 10 Microns.