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### Heat Treatment of Lithic Raw Materials: Archaeological Detection and Technological Interpretation

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Heat Treatment of Lithic Raw Materials:  
Archaeological Detection and Technological Interpretation

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May 1981

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## Introduction

A lithic technology consists of a set of techniques for shaping and working stone, and a knowledge of the properties and characteristics of the materials utilized. Lithic technology is the foundation of non-metallurgical cultures; stone is directly used in making many types of stone tools as well as indirectly in fashioning tools from other substances. Lithic technology is an important aspect for the archaeologist to study, if only for the practical consideration that on most prehistoric sites, stone tools and debitage are the only material culture preserved. Reconstruction of the lithic system aids not only in the technological interpretation of a prehistoric society. As technology is interconnected with other aspects of culture, it can be used to infer spatial patterning of activities, connections between groups through the study of long-distance trade in lithic raw materials, and aspects of social organization.

This paper is concerned with one facet of lithic technology. Because a knowledge of the working properties of lithic raw materials is prerequisite to the effective manufacture and use of stone tools, changes in the characteristics of the stone will cause concurrent changes in the rest of the technology. Heat treatment is the intentional alteration of properties of stone through controlled heating and cooling. These physical changes are exploited by selectively heating raw materials to allow the more efficient manufacture and subsequent use of tools. Heat treatment can be used to change a poor quality stone into a more workable material. In particular, heating increases the ease and control of knapping. Soft percussion and pressure flaking techniques may be used on a stone

which would be difficult to flake in the natural state. Controlled knapping of heat altered material produces larger forms, in general, than knapping of similar forms of untreated material. Heated material may be flaked to a thinner tool edge, and the resultant tool may therefore be more efficient for cutting tasks. Heat treatment of lithic raw materials thus redefines the local resources deemed usable by the flintknapper, and increases the control and sophistication of the technology.

Interpretation of the role of heat treatment in the technological system requires first an understanding of the physical basis for the changes which occur when a stone is heated. In Part One of the paper, there is a discussion of the types and properties of naturally occurring siliceous stone used as lithic raw materials. This forms the base for the explanation in Part Two of the physical changes effected by heating as discerned through replicative experiments conducted by several researchers. It is emphasized that the observable changes in the stone vary with the specific lithic type; thus it is difficult to identify a standard set of objective criteria by which heat treatment may be detected on an isolated artifact.

The effects of heating on stone leads to the enumeration, in Part Three, of several problems relevant to the archaeological detection of the practice of heat treatment. The physical effects of heating must first be differentiated from the results of natural surface alteration processes. The intentional practice of heat treatment must be distinguished from accidental or natural heat alteration. Because the changes upon heating are peculiar to each stone type, the most reliable assessment of heat treatment is made when the range of variability in the artifact assemblage is compared to that seen on experimentally heated specimens of the same source material.

Replicative heat treatment experiments elucidate not only the beneficial

aspects of heating, but also the damage from overheating stone. Based on the conditions necessary for the successful heat treatment of lithic raw materials, there is a discussion in Part Four of the types of heat treatment structures one would expect to find in the archaeological record. Examples are drawn from the ethnographic literature of aboriginal methods of heat treating stone in an attempt to discern the structural or physical correlates of the process. Cases from the archaeological literature which have been interpreted as the physical remains of heat treatment activities are discussed, followed by an investigation of several phenomena which might be more profitably viewed as the archaeological correlates of heat treatment. Finally, there is a discussion of the spatial patterning of heat treatment activities, i.e., where heat treatment occurs both within sites and, on a regional level, between various types of sites.

Part Five is an exploration of the behavioral and technological implications of the heat treatment process. After describing the models given by other researchers, I proffer my own interpretations of the potential reasons for the presence of heat treatment within a lithic assemblage. This model, based on the physical effects of heating on siliceous stone, is then tested using archaeological data from several published site reports. The problems inherent in the present reporting of heat treatment are discussed here; presenting heat treatment data in generalized terms in the site report limits the level of reliable interpretations which may be drawn.

Heat treatment of raw materials has important consequences for a lithic technology. As such, heat treatment should be analyzed as a standard practice, preferably by criteria gleaned from the experimental heating of the site's raw material sources. The prehistoric practice of heat treatment and its significance for the rest of the technology has only recently been acknowledged by archaeologists. Don Crabtree's paper and his subsequent contributions at the

Les Eyzies Lithic Conference in 1964 have led to an explosion of research in this area. One hopes that this increased awareness will lead to the investigation of heat treatment within the scope of many more lithic analyses, so that the extent of this practice prehistorically may be assessed and explained.

## Part One

### The Nature of Siliceous Stone

Prerequisite to an understanding of the changes in properties which occur when siliceous stone is heated, is a knowledge of the varieties and properties of the natural materials. A wide variety of raw materials was utilized by prehistoric knappers, ranging from high quality obsidian, agate, volcanic stone, and opalites to coarser jasper, chert and flint, chalcedony, novaculite, quartzite, and basalt (Crabtree & Butler 1964:1). Factors such as local availability and suitability for specific manufacture methods and tool functions influenced the use of one variety over another in a particular cultural context. Prior to the discussion of raw material properties, I would like to review the types of siliceous stone commonly used in lithic industries.

Siliceous stone is a form of the mineral quartz ( $\text{SiO}_2$ ). Quartz is characterized by a hardness of seven on the Mohs scale, and a vitreous or glassy luster. Although pure quartz crystal was occasionally used as a raw material, distribution and occurrence favored the use of the cryptocrystalline varieties which have a texture of grains too small to be seen with the standard microscope. Chalcedony, novaculite, jasper, chert and flint fall into this category.

Chalcedony is a general term for varieties of siliceous stone characterized by a microcrystalline fibrous structure, translucence, a waxy luster, and a mode of occurrence resulting from deposition of aqueous solutions in rock cavities. Agate is one of these varieties of chalcedony. Opal, rarely seen as a lithic raw material, has an amorphous hydrous structure and a lower hardness than



quartz (Hurlbut & Klein 1977:416, 418-20). Novaculite is a variety of siliceous stone which is thought to originate from metamorphosis of bedded chert, and is characterized by its white color presumably due to large amounts of intergranular water (Blatt, Middleton & Murray 1980:571).

Flint, chert, and jasper are dense granular silicate aggregates distinguished by their fine-grained homogeneity. Jasper is often diagnosed by its high hematite impurity content which colors the stone red. Structurally, chert and flint are similarly composed of small quartz granules surrounded by interstitial water, not interstitial opal as was once believed (Folk & Weaver 1952). In origin, both chert and flint appear to be deposits of oceanic sediment or the result of secondary formation of siliceous solutions replacing limestone (Hurlbut & Klein 1977:417). The marine origin of chert and flint appears to be volumetrically the most important, resulting mainly from the deposition of siliceous skeletal material (Blatt, Middleton & Murray 1980:577). Chert and flint are enigmatic materials as far as knowledge of the details of structural homogeneity and of original formation; this complexity is reflected in the variety of named types.

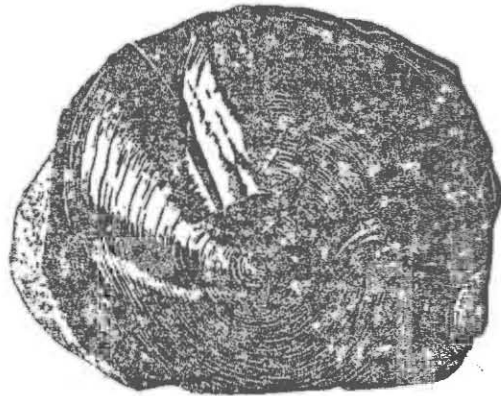
The terminology which distinguished between "chert" and "flint" is both confused and inconsistent. Many definitions are offered to distinguish the two: chert is lighter in color than flint; chert is found as nodules in a limestone matrix while flint is found bedded in a chalk matrix (Rosenfeld 1965 as cited in Sheets 1977); chert is a variety of flint or vice versa (Ellis 1940:1); and "chert" relates to materials in the Americas while "flint" more often is used to designate comparable materials in the Old World. In view of the entrenched terminological debates, I will employ the term "chert" for both varieties of an essentially identical substance. Furthermore, because the balance of experimental replication of heat treatment has utilized cherts, many

of the changes discussed in reference to heat treatment will refer specifically to chert but may pertain to other varieties of siliceous stone as well.

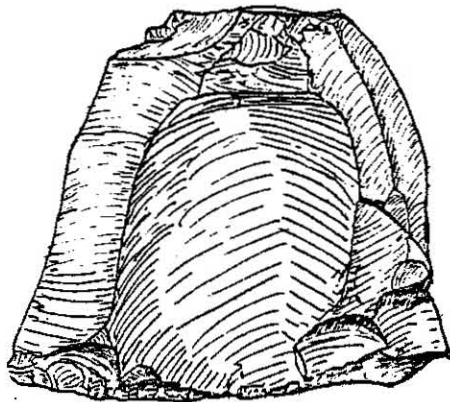
Cryptocrystalline varieties of siliceous stone possess several characteristics necessary for use in a chipped stone technology. First, these materials are hard in comparison with the substances normally worked with stone tools. Because they are composed of microscopic grains, these stones are relatively homogeneous and behave more or less like isotropic materials (e.g. glass) in which the physical properties do not vary with direction. Thus cryptocrystalline materials break with a conchoidal fracture when knapped, showing a smooth curved surface (see Figure 1), instead of parting along lines of internal structural weakness (e.g. as with sheets of mica). The conchoidal fracture is a diagnostic property of the cryptocrystalline varieties of quartz, and is important in stone tool manufacture because the stone may be flaked in any direction. When discussing the working properties of lithic raw materials, it is easiest to see the significance of the physical properties if the varieties of stone are compared on a continuous scale. One such scale, based on ease of workability, is offered by flintknapper Errett Callahan (1979:16) and is shown in Figure 2. Here the qualities of toughness, strength, and elasticity are interrelated with various grades of lithic materials. Because this proposed scale is based on the subjective judgment of the flintknapper and is a relative scale, it is closer to the emic reality of prehistoric flintknappers than a quantified scale would be.

In evaluating the workability of a lithic material, the most important characteristics to consider are the toughness (versus brittleness) of the stone, and the elasticity or flexibility and strength of the material (Crabtree 1967:8-9; Healy 1966:5; Callahan 1979:16). The first criterion of toughness or brittleness determines the "amount of resistance to the necessary force

Figure 1  
Conchoidal Fracture



a. Conchoidal fracture of obsidian.  
(after Hurlbut and Klein 1977:184)



b. Chert core showing typical curved  
flake scar surfaces. (after Shippee 1963:272)

Figure 2  
Relative scale of siliceous stone types (after Callahan 1979:16).

Criteria: Ease of Workability

|   |                                   | <u>GRADE</u> | <u>SUGGESTED MATERIALS</u>  |
|---|-----------------------------------|--------------|---|
|   |                                   | .5           | Opal, some cold asphalts, some very hard candies  |
| Usual Limits of Flaked Stone Tool Lithic Materials<br>Limitations of Fabricators for Secondary Thinning | Antler Billet<br>Soft Hammerstone | 1.0          | Obsidian (as Glass Butte, Oregon), glass, ignimbrite, some opalites   |
|   |                                   | 1.5          | Coarse obsidian (Wagner Quarries, Coconino Co., Az.), tektite, pitchstone   |
|   |                                   | 2.0          | Fine-grained basalt (Wagner, Az.)   |
|   |                                   | 2.5          | Heated Georgetown flint (Tx.), other heated finer flints, less fine-grained basalts   |
|   |                                   | 3.0          | Finest flints (Georgetown, Texas; Brandon, England; Dover, England)   |
|   | Wooden Billet<br>Pressure Flaker  | 3.5          | Finer cherts, chalcedonies, agates, jaspers (Flint Run), novaculites (Ark.), and silicified woods, Spanish diggings (Wyo.) quartzite (silicified sandstone), Grand Pressigny flint (France), Indiana hornstone. <u>Most lithic materials</u>                                |
|   |                                   | 4.0          | Silicified slate (Stanley Co., N.C.), andesite (N.J.), coarser cherts (Williamson, Va.; Belton, Tx.), chalcedonies, agates, jaspers, and novaculites (Ark.), finer Hixton quartzites (Oshkosh, Wis.), siltstone, bloodstone, porcelain, silicious limestone, quartz crystal |
|   |                                   | 4.5          | Coarser Hixton quartzites (Oshkosh, Wis.) and silicified slates, finer rhyolites, milky quartz (bull quartz), argillite.  |
|   |                                   | 5.0          | Coarse quartzite (Va.), coarse rhyolites, felsites, common basalt   |
|   |                                   | 5.5          | Catoctin Greenstone (Va.), coarser felsites   |

Note: Thermal alteration seems to raise most amenable materials .5 to 1.0 higher in the scale. A 1.5 raising may be possible under optimum conditions.

required for detaching a flake" (Crabtree 1967:9). Obsidian and glass are considered as the most brittle, while agates and quartzites are usually placed on the tough end of the scale. The properties of strength and flexibility allow the knapper to detach long thin flakes rather than having them break off short with a hinge or step fracture (Crabtree 1967:8). Cryptocrystalline materials in general are stronger than other stone materials such as limestone, sandstone, and granite; this has been shown to be the result of the very fine grain structure (Iler 1963).

One of the most useful attributes for determining workability is the degree of luster seen on a freshly flaked surface of the stone (Crabtree 1967:9). Luster refers to the surface appearance of a mineral in reflected light (Hurlbut & Klein 1977:189). This property is related to the crystalline texture of the stone, the size of the grains, such that there is a correlation between high or vitreous luster found on obsidian with its extremely fine-grained or non-crystalline texture. Healy (1966:6) explains that

the touch can determine the extremes of lustre by the feel of a very slick surface of a good vitreous lustre to the smooth, but slightly clinging or dragging tendency on a very dull stone surface. If the fractured surface appears to be grainy then the crystals are developed enough so that the stone probably is unusable for the purpose of tool or weapon making.

A stone with high luster on its flaked surfaces will have less tenacity or toughness, and also more strength, than a stone with a dull, grainy surface. Thus the observed properties of a stone directly relate to the workability, and to the manufacture methods used (Crabtree 1967:8). Control of flake characteristics allows the flintknapper to make a wide range of tool forms.

## Part Two

### Effects of Heating on Siliceous Stone

There are several natural mechanical and chemical processes which can alter the surface characteristics of siliceous stone. Prior to the investigation of heat treatment in a specific cultural context, the lithic analyst must be able to distinguish heat-altered chert from that either unaltered or altered by other natural phenomena. Recently, a large literature has built up describing changes which occur from the heating and subsequent cooling of siliceous stone. Although trends are seen in the changes between experimental replications, it must be emphasized that the presence and degree of the changes varies with the specific types of stone and with the heating conditions to which the stone is exposed.

The most easily observable effects of heating are the changes in surface characteristics of color, texture and luster. Changes in fracture mechanics of heated stone are reflected in flake and flake scar patterns, and in fracture patterns of over-heated material. While the former changes are important criteria in differentiating heated and unheated material, the changes in knapping properties are more important in the technology of making and using stone tools. In this section, I would like to describe changes in heated siliceous stone as determined by experimental replications. For a summary of experimental results on different stone types from a survey of the literature, see Appendix.

The change in heated chert to a pink or reddish hue is a hallmark of the heat treatment process. However, a variety of reactions have been observed on

different materials. The general reddening has been noted by several studies (Mandeville & Flenniken 1974:147; Purdy 1974:46; Sollberger & Hester 1973:182; Crabtree & Butler 1964:2; Perino 1971; Behm & Faulkner 1974:273; Rick 1978: 21-30). Other cherts react differently. Fitting et al (1966:36) found that when heating Bayport chert, which outcrops in the lower peninsula of Michigan with a natural color range of white through gray, each shade darkened approximately one Munsell shade. Burlington formation cherts, from limestone beds along the Mississippi River system, demonstrate a trend of lightening in color or increasing in value (Rick 1978:59). Some varieties of chert exhibit no color change when heated. Thus, lack of a color change in certain cherts does not indicate the absence of heat treatment (Collins & Fenwick 1974:135; Helms 1981).

An examination of the cause of the color changes can explain this variety of response. Many cherts appear colored due to the presence of iron oxide impurities (Frondel 1962 as cited in Mandeville 1973:197). Klippel (1970:4) reports that the brown coloration in cherts is due to traces of goethite ( $\text{HFeO}_2$ ), a hydrous iron oxide impurity. When heated this alters to hematite ( $\text{Fe}_2\text{O}_3$ ), imparting the red or pink color. Analysis of the iron content of various Florida cherts by atomic absorption tests led B.A. Purdy to quantify the correlation between iron content and post-heating color: cherts with .40% iron changed from pale yellow-brown to reddish brown; those containing .25% Fe changed from light gray to pinkish gray; and those containing .11% Fe exhibited no color change (Purdy 1974:46; Purdy & Brooks 1971:323).

The influence of the variable of heating temperature has also been investigated. Color change occurs between 240-260° C. in Florida chert types and between 230-290° C. in Burlington (Illinois, Missouri) chert. In both cases this temperature is lower than that required to alter other properties in these

cherts such as luster and "workability" (Purdy 1974:46; Rick 1978:18). It does not appear that the rate of temperature change or peak temperature reached in the heating experiment affects the degree of color change as long as this critical range is reached (Rick 1978:19).

Color change also seems to be affected by the amount of weathering and patination on the stone. On weathered pieces, the color change seems greater at or just below the cortex or weathering rind (Collins & Fenwick 1974:137). Colors on unworked chert may only be a surface phenomenon, as with patinated specimens, while colors induced by heating tend to permeate the piece; thus color is best estimated from fresh breaks on a hand sample (Sollberger & Hester 1973:182).

Since the value of using color change as a criterion of heat treatment is limited by the close relationship of the change to the specific chert, this criterion is most reliable when used in conjunction with other criteria in comparisons between heated and unheated specimens of the same chert type.

The second and probably best indicator of change in heated cherts is an increase in surface luster, variously described as a "greasy," "glossy," or "vitreous" luster appearing on flake scars which have been exposed by flaking after heat treatment (Crabtree and Butler 1964:1; Flenniken & Garrison 1975: 129-30; Perino 1971:99-100; Purdy 1974:43-44; Mandeville 1973:191; Mandeville & Flenniken 1974:147; Sollberger & Hester 1973:182). The fact that luster changes are only revealed in subsequent flaking means that heat treatment is distinguishable from other natural surface alterations which create changes in the luster or texture on external surfaces of the artifact only. Because there is such a range of lusters observed on naturally occurring siliceous stone types, the increase in luster upon heating is a relative property, qualified by comparison of natural and heated samples of the same chert type.

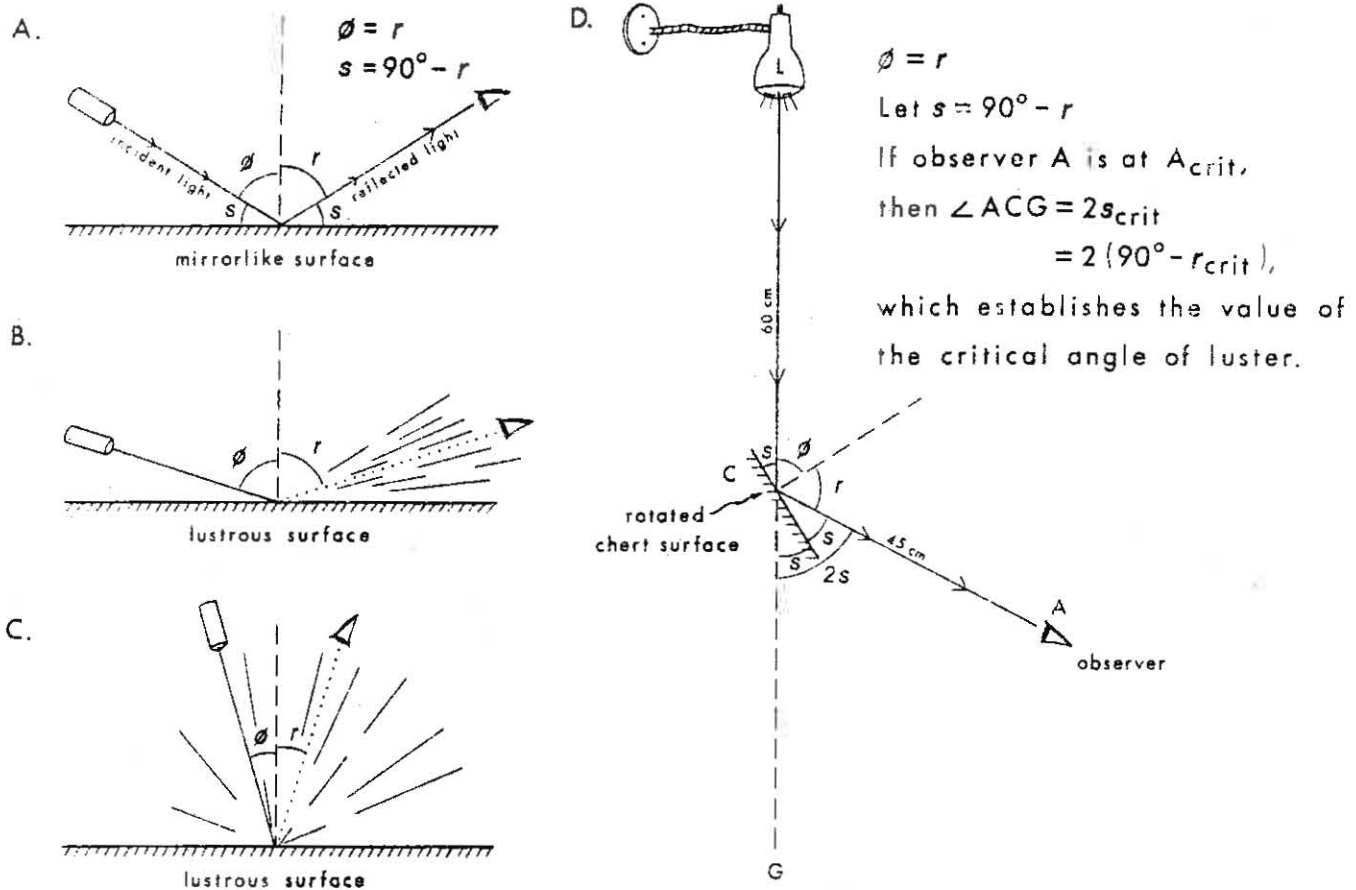


As described above, luster is a property tied to the crystalline texture of a siliceous material such that a grainy or rough surface scatters more light and thus reflects back a smaller portion than does a lustrous surface. In an attempt at quantification of this phenomenon of "increase in luster" on heated cherts, Rick (1978:15-17) developed a method of measuring luster by shining a light source at a piece of chert and measuring the critical angle at which the bright luster of the surface obscured the natural color of the chert (see Figure 3). The more lustrous the object, the larger this critical angle. On a smoother and more lustrous fine-grained chert surface, the critical angle of luster is greater than that of a coarse-grained sample with low luster (Rick 1978:17).

Although there are doubts as to the replicability of this system of luster measurement, this work does represent the only attempt at quantifying and objectifying the description of the "vitreous," "glossy," or "greasy" luster which appears on heated chert. As it stands, assessment in this important effect of heating remains the subjective qualification of the experimenter; at the present stage of research, determination of heat treatment of a particular chert type relies on the comparisons of experimentally heated materials with naturally occurring materials. Adopting a more quantified system when analyzing heat treatment would standardize results and allow clarification of a more reliable criterion than "increase in luster."

Each chert responds differently to heating; the temperatures and times of heating and cooling needed to effect the luster change depend on the particular chert type (Crabtree & Gould 1970:194). Thus a large part of the recent literature has developed with an express concern for documenting the critical temperatures involved in luster change in different cherts. Results range from 260° to 600° C., depending on the substance tested in the study. Several fac-

Figure 3  
 Method of measuring luster.  
 (after Rick 1978:17)



If observer A is at  $A_{\text{crit}}$ ,  
 then  $\angle ACG = 2s_{\text{crit}}$   
 $= 2(90^\circ - r_{\text{crit}})$ ,  
 which establishes the value of  
 the critical angle of luster.

Method of measuring luster. (A) Reflection of a light beam from a mirrorlike surface. (B) Light scattering from a lustrous surface, large angle of incidence. Light is scattered slightly, but reflection is concentrated along the specular angle of reflection. (C) Light scattering from a lustrous surface, small angle of incidence. Light is widely scattered so that observer at specular angle of reflection sees little or no gloss. (D) Method of measuring critical angle of luster. For each position of the observer A, position of chert at C is adjusted to give maximum gloss. Observer moves upward, adjusting chert angle at each step, until reaching a point at which color-obscuring gloss can no longer be seen after rotating chert or, if present, is not brilliant enough to obscure natural color of chert. At this position,  $\angle ACG = 2s_{\text{crit}} = 180^\circ - 2r_{\text{crit}}$  is defined as the *critical angle of luster*. More lustrous cherts have larger critical angles.

tors affect the temperature needed to alter luster properties. First, it appears that finer-grained materials alter at a lower temperature than do coarse materials (Mandeville 1973:191). In addition, the size of the chert sample exposed to the heat affects the results, with small or thin flakes altering more quickly and more evenly than thick chunks or nodules of material (Crabtree & Butler 1964:2). Several observations indicate the effects of temperature: (1) luster changes gradually as temperature is raised rather than being an instantaneous change; (2) luster change may be dependent on length of time the material is held at the peak temperature; and (3) rate of temperature change does not seem to affect completeness of luster change (Rick 1978:19). Finally, some materials do not exhibit any change in the property of luster after heating. In particular, experiments using quartzite have shown that this material responds to heat treatment with a color change but rarely changes in other properties, including luster (Toll 1978:62; Behm & Faulkner 1974).

It has been shown how the degree of luster in a siliceous stone bears a direct relationship to the structure and texture of the stone. However, there is exhibited in the literature a confusion over the explanation of the causes of luster change in heated materials. Investigations of this problem have focused on two hypotheses: recrystallization, a structural change; and loss of chemically bound water and a fusion of microgranules in heated cherts. Since the change in luster occurs within the same critical temperature range as changes in the ease of workability of heated cherts, this question of causation is central to the understanding of the physical basis for heat treatment. Numerous analytical methods have been employed to investigate this problem with mixed results; the debate over whether heat treatment causes structural or chemical changes in siliceous stone remains at issue. I would like to describe some of the empirical results of these investigations to provide a base for the

later discussions of the significance of changes in knapping properties of heat treated cherts.

Chert is a relatively homogeneous and fine-grained substance and is thus difficult to assess by standard petrographic or optical thin-section analysis. Although Crabtree and Butler (1964:2) indicate that recrystallization is observed in thin-sectioned heat treated chert samples, more recent investigations conclude that no change in crystal size or orientation is observable in heated cherts (Mandeville 1973:198; Purdy 1974:50).

X-ray diffraction analysis is usually used to determine the internal structure or crystalline lattice of minerals. Thus it is the preferred method for determining whether the microstructure of chert is altered by heating, either by a reorientation of the crystal lattice or by actual breaking and reformation of lattice bonds. Purdy (1974:50) maintains that there are no significant differences in the XRD patterns of unheated and heated chert samples. Similarly, Rick (1978:34-35) finds no significant changes in structure between heated and unheated control specimens. However, in a detailed study Weymouth and Mandeville (1975:62)

examined a number of thermally treated chert samples with X-ray diffraction and have observed, in many cases, a significant [diffraction] line broadening [indicating a decrease in crystal-line order]. The reason previous attempts failed to disclose a measurable effect on X-ray diffraction lines due to heat treatment is that the effect is small.

In comparing unheated samples with chert heated first to 400° C. and then to 800° C., it was noted that the "effective crystal size" decreased in the samples heated to 400° C., although not significantly in all cases, while crystal size decreased significantly in all the samples heated to 800° C. (Weymouth & Mandeville 1975:64). These results are important. However, it must be emphasized that 800° C. is beyond the apparent heating temperatures used ethnogra-

phically or prehistorically. Since the melting point of  $\text{SiO}_2$  is  $1728^\circ \text{C}$ . (Mandeville 1973:198), well beyond normal heat treatment temperatures, the effects of recrystallization may not be active here; rather possible explanations for the XRD results may lie in either a decrease in crystal size due to microfractures, or because there is "an effective spreading of inter-atomic distances due to non-uniform, local strain" (Weymouth & Mandeville 1975:66).

Many investigators have detected a loss of weight in specimens after heating (Mandeville 1973:193; Purdy 1974:37-40; Rick 1978:33-34; Helms 1981; Mandeville & Flenniken 1974:147). Dehydration of interstitial water is usually suggested as the cause of this weight loss. Weymouth and Williamson (1951) noticed a continual weight loss in cherts when heated, with a jump in weight loss between  $350^\circ$ - $500^\circ \text{C}$ . corresponding to a drop in the measured density in the same temperature range. Similarly, it is in this range that the property changes such as luster increase and increase in "workability" also occur. It has been observed that heat fracturing and explosion commonly occur within this critical temperature range, because of the rapid loss of water caused by dramatic increases in temperature (Purdy 1974:41-42). Thus it appears that the loss of chemically bonded water is a significant factor in the physical alteration of cherts by heating, although explanations of the effects of water loss are not clear beyond this observed correlation.

The most dramatic results have emerged from the comparison of heated and unheated chert samples by scanning electron microscopy. Through this technique of high-power magnification of freshly fractured surfaces, details of surface morphology and "topography" may be examined which reveal the surface heterogeneity of chert. Comparison of heated and nonheated specimens show that on unheated chert, fracturing occurs predominantly around the microgranules, while in heated chert there is a propensity for microfractures which split individual grains (Purdy 1974:51; Mandeville 1973:198; Rick 1978:35-39).

Thus the surface appears smoother in texture even though there is little documentation of a decrease in individual grain size. While this transgranular fracture is often observed, there is no consensus as to the cause of it. Purdy and Brooks attribute this fracture pattern to a bonding or fusion of the grains by means of a "flux" of intercrystalline impurities which reach a eutectic melting point at much lower temperatures than quartz; the binding together of quartz microcrystals by the interstitial impurities creates a more homogeneous material with a "fracture like glass rather than like a rock aggregate" (1971: 323). Mandeville (1973:199) explains the change in fracture by a recrystallization of the interstitial matrix in which "matrix fibers appear to have melted and fused together, incorporating the granules and filling the intercrystalline spaces to produce a more nearly homogeneous material." In experiments with novaculite, Flenniken and Garrison postulate that the more homogeneous nature of heated stone is due to "a more uniform density of microfractures which makes possible a more uniform distribution of internal stresses in the stone," (1975:129). Thus, while the physical processes are as yet uncertain, the effects of heat treatment are commonly a more homogeneous body which fractures cleanly with a smoother flake surface than in unheated stone.

The final area of analysis investigating the effects of heating on siliceous stone are the tests of mechanical strength of heated versus nonheated stone. Purdy (1974:47-49) has compared heated and nonheated samples of the same types of stone in compressive strength, measuring pounds per square inch of pressure which can be exerted on a cube of the sample until it breaks, and in point tensile strength, in which pressure is loaded on one point of a stone coring until fracture occurs. Point tensile strength is more important in lithic analysis because the force needed to fracture stone in the manufacture of stone tools is essentially the same type of force as applied in the point

tensile strength tests (Purdy 1974:49). The results indicate that unheated cherts withstand more localized pressure than heated samples; there is a reduction by 45% of the force needed to fracture the heated material, and an increasing reduction of point tensile strength with increasing heating temperatures (Ibid:48-49). However, there is an increase in the compressive strength of heated and slowly cooled materials. Purdy (1974:49) explains this apparent contradiction:

The increase in homogeneity which increases strength under compression is the very factor which decreases point tensile strength: (1) the individual microcrystals are bound more firmly together; (2) therefore when a flaw is introduced which is preliminary to and necessary for fracture to occur, (3) failure takes place more readily because the specimen fractures more like glass. . .

Thus from the strength tests it appears that there is a decrease in force necessary to induce fracture in heated siliceous materials. This property of brittleness or tenacity in a lithic raw material has been described as one of the most important criteria in choosing a good stone for knapping (Crabtree 1967:9). The correlation of smooth lustrous flake surfaces with a decreased tenacity or resistance to fracture is significant in the workability of a high quality raw material. The increase in luster and decrease in point strength in heat treated materials therefore confirms the subjective judgment of flint-knappers of the increased workability of heated material.

The improved "workability" of heat treated stone has frequently been mentioned by experimenters working with both heated and unheated samples of the same stone (Crabtree & Butler 1964; Mandeville & Flenniken 1974:147; Sollberger & Hester 1973:181; Patterson 1979b:12). However, this criterion is relative: the change in fracture properties of a heated chert can only be gauged by comparison with the same chert unheated, as the variation in workability between

types of natural siliceous stone overlaps the range of variation seen between heated versus nonheated. In other words, when an originally tough raw material is heat treated, it may more closely resemble a high quality (untreated) stone in workability.

In comparisons of flake and flake scar characteristics on heated and unheated samples of identical cherts, several effects of heating are seen which are significant for the manufacture of stone tools. First, the observation is made that flake scars of heated chert have many small ripple marks or more sinuous ripple marks than those on untreated stone (Klippel 1970:4; Collins & Fenwick 1974:138). These "ripples of percussion" are absent on blocky fragments produced by heat fracture (Fitting et al 1966:24). Rick (1978:51 and Fig. 19) notes that these ripple marks are always present on the flake scars of pressure flaked obsidian or glass, indicating that heat treated chert "more closely approximates pure noncrystalline silica."

Because of the decrease in force needed to knap heated materials, manufacture is easier by both percussion and pressure techniques (Collins 1973:464). Using percussion, it is possible to detach flakes with light taps while unheated material necessitates strong blows (Rick 1978:46). Crabtree noted several times the ease with which he was able to pressure flake heated materials which in their natural state were tough and "extremely difficult" to flake (Crabtree & Butler 1964:1). Because of the brittleness of heated chert and the thin edge potential, there is a disadvantage to flaking heated materials because of the reduced edge strength; the edges sometimes cannot withstand the pressure and collapse or crumble. This can be remedied by grinding or dulling the striking platform prior to pressure flaking (Rick 1978:51).

In experiments replicating knapping of identical forms with both heated and control material, flake size and morphology show the effects of heat treat-



ment. Longer and larger flakes seem to be produced on heat treated cherts; the flakes show a tendency to travel further across the heated preform surface upon detachment, with less failure from step or hinge fracturing (Mandeville & Flenniken 1974:147; Rick 1978:47,49; Sollberger & Hester 1973:181). While flakes are larger, there is some indication that heated flakes are also thinner. The larger length:thickness and length:width ratios of heat treated flakes is interpreted as finer control over knapping (Rick 1978:49-51). Patterson (1979a) quantified the differences between heated and non-heated flake characteristics on stream cobble cherts from Fayette County, Texas. Several general trends appeared: (1) heating produced larger size flakes; (2) there were higher weight percentages in most size categories because nonheated chert frequently flaked with very small size debris "chewed off" the edges; and (3) within a given size category the range of flake thicknesses tended to be greater after heat treatment, which might "reflect a better ability to vary flake characteristics after heat treating." The significance of this increased control of knapping will be discussed in greater detail later.

Thus far we have been concerned with the beneficial aspects of heat treatment, i.e., the increased luster, more homogeneous texture, decrease in force needed to detach flakes, and greater ease and control over flaking properties enabling longer, thinner flakes to be knapped without without breaking off short in step fractures. However, when siliceous stone is overheated, several phenomena such as cracking, crazing, potlidding, and heat fracturing occur which render the stone unfit for manufacture into tool forms. These destructive effects are produced when chert is exposed to the direct heat of the fire, due to the inability of siliceous stone to adjust to rapid and extreme temperature changes. Through experimental replication of heat treatment, researchers have discovered the conditions under which heating a particular stone

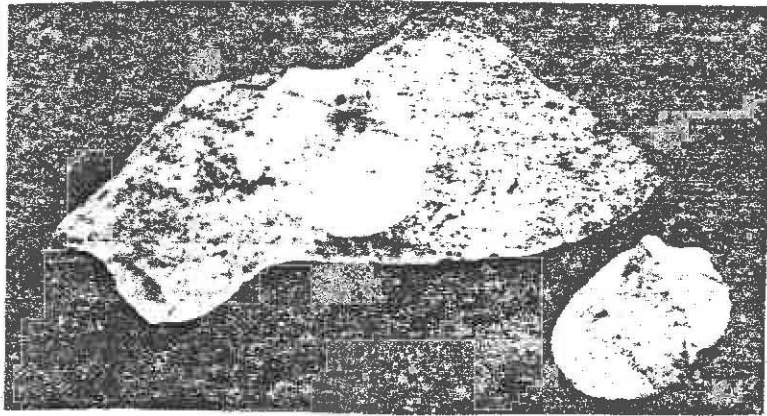
is successful. From this literature, we can generalize the necessary methods for successful heat treatment.

It has long been observed that direct exposure to heat has destructive effects on stone (see Figure 4). Brinton (1884:279) writes of the discoloration, scaling, and "peculiar" fracture forms of overheated stone, with quartzite fracturing in angular pieces with rough friable surfaces, and jasper splitting or splintering into fragments exhibiting no bulbs of percussion. According to Ellis (1940:54,59), chert in an open fire will shatter and "exfoliate" due to the sudden heating and cooling; pieces not broken are

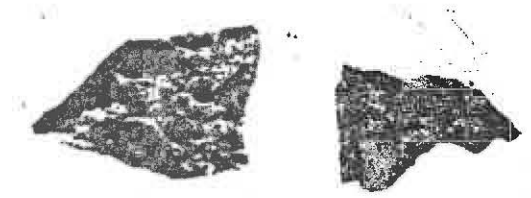
so filled with tiny fire cracks and the surfaces of the material so roughened due to differential expansion of the crystals caused by heating, that it is impossible to use it to any practical advantage in the shaping of stone implements.

Besides the irregular and jagged fragments produced by overheating, potlids, or "round, lenticular pieces," are detached from the main body of stone, these "pseudo-flakes" distinguished by the absence of striking platforms, bulbs of percussion, and ripple marks (Crabtree & Gould 1970:191; House & Smith 1975:78).

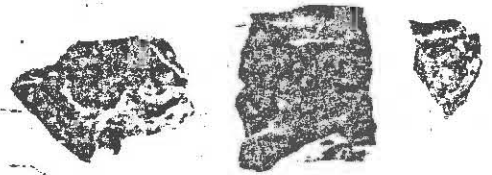
Crazing and potlidding can be produced by extremes of either heat or cold. Potlid fractures have been observed associated with the spheroidal weathering of rocks through frost cracking and the effects of freeze-thaw cycles (Hammett 1975). In mountainous areas where there is daily alternation between freezing and thawing, water in cracks expands as it freezes, resulting in frost-wedging of rocks (Blatt, Middleton & Murray 1980:247). The extreme cold can produce potlid fractures similar in morphology to those caused by heating, because the mechanical processes are similar: fracture caused by expansion and contraction of intergranular and interstitial water in the stone with the extremes in temperature. According to Purdy (1974:40,45) a rapid rise in temperature, pre-



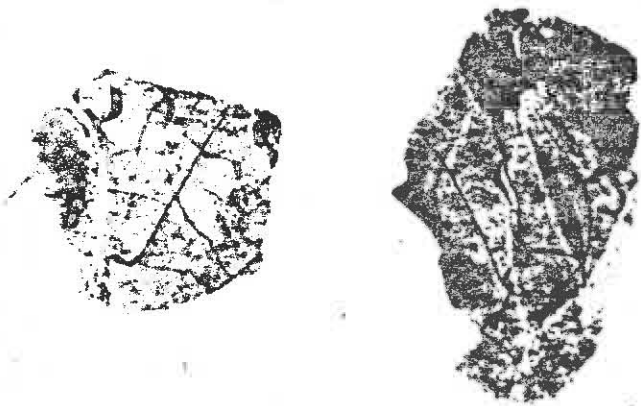
(a)



(b)



(d)



(c)

Figure 4. Examples of heat damaged cherts. (after Purdy 1975: Plates 2,3,6,7).

- a. potlid fracture
- b. blocky fracture flakes and potlids
- c. heat crazing
- d. heat cracking



empting the gradual dehydration of chemically bound water, causes explosion when the internal stress exceeds the elastic limits of the stone material.

Purdy has done extensive experimentation pertaining to the heating conditions under which Florida cherts result in explosion rather than beneficial heat alteration (1974:40-45). Observation of experimental test firings reveals that explosion occurs with Florida cherts in several heating situations (Purdy 1974:40-42):

- (1) when samples were rapidly heated to 400° C.
- (2) when samples were removed hot from the oven after being rapidly heated
- (3) when samples were put into an oven preheated to 400° C.

However, there are several circumstances under which either less frequent explosion or no explosion occurs:

- (1) explosion was rare when samples were heated slowly, even if removed from the oven hot
- (2) no explosion occurred if samples were heated rapidly to 350° C. and then the temperature slowly raised to 400° C.
- (3) explosion never occurred when reheating samples to the same temperatures.

These observations led Purdy to conclude that 350-400° C. was the "critical temperature" for Florida cherts, the point at which the interstitial water is lost, explosively if the stone is rapidly heated and constructively if gradual heating is maintained. Even though the color changes in Florida cherts at 240-260° C., it is within the critical temperature range that water loss and explosion occur if the chert is rapidly heated, and vitrification or the development of a luster on fractured surfaces occurs if controlled heating takes place (Purdy & Brooks 1971:323).

Additional experiments have corroborated these results that there is a certain critical temperature for each siliceous stone type at which many of the physical properties of the stone are altered. It appears that the intensity

and duration of heating are primary factors in the success of heat treatment, although rapid cooling has been observed to produce cracking or crazing of some materials (House & Smith 1975:87; Crabtree & Butler 1964:2). In addition, it has been shown that the critical temperatures and success of the heating process differs between specific raw materials and that the success of heat treatment varies according to the size of the stone heated.

Don Crabtree has experimentally heated many different types of siliceous stone. He writes (Crabtree & Butler 1964:2):

After considerable trial and error, I learned that silica minerals varied considerably in the length of time and amount of heat necessary to bring about the desired change. Some types required comparatively low temperature; others required higher temperatures. For each type of silica mineral there appeared to be a critical temperature range below which, regardless of length of time involved, no change would take place and above which it would crack or craze. On the other hand, some of the minerals had to be held in the critical temperature longer than others in order to bring about the desired change.

Moreover, different cherts have a wider critical temperature range than others. In experiments with Flint Ridge (Ohio) chert, Pickenpaugh and Collins (1978) successfully heat treated the material at 350° C. Experimenting with the same type of chert, Patterson (1979c:33-34) was able to obtain similar results by heating the chert to 260° C.; he concludes that "a very narrow temperature band is not required for adequate thermal alteration of Flint Ridge materials." Thus the temperatures necessary for successful heating depend on the specific raw material used. In addition, the size of the chert "package" or the relative thickness of the specimen affects the success rate of the heat treatment operation. "Spalls, cores, and roughed out blanks that are comparatively thin can be heat treated more successfully than thick chunks or nodules. The thicker pieces do not heat or cool evenly and, as a result, crack or craze rather

easily" (Crabtree & Butler 1964:2). This observation holds important consequences for the place of heat treatment in the manufacturing reduction sequence, as will be discussed in greater detail later.

Therefore we have several factors which are preconditions for the successful heat treatment of siliceous materials. It becomes apparent that "the thermal treatment process is considerably more complex and sophisticated than simply dumping the stone into a fire" (Crabtree & Gould 1970:194). The heating conditions, the tolerances of specific cherts, and the size of the chert package heated all combine to affect the success of the heat treatment operation; these I expect will also have effects on the methods of heating, the structure in which heating occurs, and the spatial placement of the heating station both within and between sites. I would like to summarize this section on the effects of heating on siliceous stone by stating several predictions for conditions of optimum heat treatment.

First, success of heat treatment is dependent on the degree to which the heating process can be controlled. This means that the temperature changes must be gradual, and the firing conditions must be such that the critical temperature can be reached and maintained. In order to ensure gradual and even heating of the stone, it must be insulated from the direct action of the fire; this may be accomplished by engulfing the chert in a layer of sand, or by burying the chert in the soil beneath the fire. Gradual heating and cooling takes time, anywhere from 12 to 48 hours in the experimental situation. Thus the fire must be maintained for a long period of time, and the heating structure allowed to remain undisturbed for an equal amount of time for gradual cooling. Finally, controlled and even heating will be most successful with thin small pieces rather than large thick pieces.

Second, successful heat treatment implies different conditions for differ-

ent chert types. Through empirical familiarity with a particular type of stone, both aboriginal and modern technologists must determine the specific critical temperature range for that type. Because the conditions necessary for success in heat treatment vary in detail between chert types, we can expect slight variation in the physical structures used as heating stations; likewise, because of the process itself, intact structures may be rare in the archaeological record. Finally, different local materials will be associated with varying degrees of care and control in the heating process because of the different ranges of tolerances to temperature change of different stone types.

### Part Three

#### Archaeological Detection of Heat Treatment

The experimental replication of heat treatment has sparked interest in two basic problems. First, there is the problem of the detection of this process in the archaeological record. Second, there is the problem of interpretation of the process of heat treatment as a behavioral phenomenon in lithic technology. In order to analyze heat treatment in a given cultural context, the archaeologist must be able to use reliable criteria for documenting the presence of the process, either from the artifacts themselves or from their context. A discussion of the methods of detection is in order here, as the reliability of the interpretations is contingent on the detection of heat treatment in an assemblage.

Replicative studies document the effects of heating on stone. However, an increased awareness of the variable nature of these changes from one chert type to another has brought to light several problems concerning the archaeological detection of heat treatment. First, there are several natural mechanical or chemical processes which cause glossy surfaces on chert. How does the archaeologist differentiate between these processes from the end results and segregate the products of heat treatment? Secondly, once the analyst has a segment of the lithic assemblage presumably heat-altered, the major problem becomes how to differentiate between natural or accidental heat alteration and intentional heat treatment, i.e., a cultural selection for certain physical properties changed by heating. Finally, there is the problem of the methods of detection of heat treatment within a given lithic assemblage. Since the effects of heat



are peculiar to a given chert type, the only reliable detection method is comparison between experimentally heated raw material and the range of variation demonstrated by the lithic assemblages. The comparative method assumes that the raw material source is known (often not the case in real situations) and makes determination of heat treatment from the isolated artifact (e.g. from a museum collection) untenable. These problems will be investigated here in greater detail due to their significance for interpretations of heat treatment.

The first problem concerns the differentiation of natural surface alteration from the effects of heat treatment. At the present state of heat treatment research, determination of heating is usually made on visual criteria such as color change, increased luster, and ripple-marked flake scars. Any natural processes which produce similar surfacial changes will confound the issue. Here I will focus on natural phenomena which impart surface glossiness to siliceous stone: patination, mechanical abrasion or polishing, "desert varnish," and polish from use.

Patination is a general term for several types of weathering processes affecting the surface of chert. Weathering can produce surface changes in both color and texture. A patina on weathered chert seems to be the result of several factors: sunlight and surface exposure (Semenov 1964:11); the solvent action of acidic or alkaline groundwater solutions (Curwen 1940:435-436; Schmalz 1960:49; Rottländer 1975:106); and mechanical weathering (Ray 1947). Patination can be more developed under certain environmental conditions, and in general increases in thickness with time. The large literature in this area has developed to investigate the potential of using degree of patination as a relative chronological indicator, but the complexity of the process has hindered tangible results.

Patination is thought to affect chert by etching the surfaces and making

It may be that the effect of heat treatment on weathering differs from a semi-arid to a humid environment (Collins & Fenwick 1974:136). Clearly more work needs to be done in this area. Especially in the Paleolithic of the Old World, where the age of the deposits increases the occurrences of patination, the synergistic effects make the detection of heat treatment in the presence of patination all the more difficult.

In addition to the potential confusion of patinated artifacts, there are a variety of mechanical processes which affect lithics after deposition to create glossy surfaces. Here I will discuss briefly mechanical "polishing" by sand, abrasion by water, "desert varnish," and use-polish. Mechanical polishing by sand or dust carried by wind is a process which results microscopically in a pitted surface. This process eventually obliterates flake ridges, edges, and protruberences, and causes a polished surface appearance (Borden 1971:9-10; Stapert 1976:14). Wind polishing of this type is the cause of faceted pebbles in glacial plain deposits, and gives artifacts in desert environments an overall polished appearance (Witthoft 1955:23-24).

The frictional abrasion of sand and pebbles in cryoturbated soils can produce a glossy polished surface on artifacts similar to that effected by wind polish. To the naked eye, the surface appears smooth or polished, but under the microscope the surface is covered with scratches and striations (Witthoft 1955:20; Semenov 1964:11). Water-worn cobbles likewise may appear polished to the unaided eye but under microscopic examination are covered with small pits and scratches; water-worn stone is polished more by the abrasion of particles carried in the moving water than by the erosional action of the water itself. Friction between stones is also thought to produce small patches of very high gloss on the stone (Stapert 1976:29-30).

"Desert varnish" is actually not often confused with heat treatment luster,

but will be discussed here because the term connotes a lustrous surface, which may or may not be present. Desert varnish is a black or brown stain of iron and manganese oxides deposited on the surfaces of various kinds of stone. The deposition of oxides occurs on all exposed surfaces, and is most developed in arid regions (Hunt 1954:183; Harner 1956:42). Desert varnish is a chemical process, unlike the polishing and abrasion by mechanical processes discussed above. Because of its predisposition in arid environments, desert varnish may accompany wind polish on exposed lithic debris, and here may be confused with a heat treatment luster.

Finally, localized glossy surfaces may appear on artifacts as a result of use-wear. Certain tasks such as woodworking may produce a surface which appears polished, restricted to the used edge of the tool (Witthoft 1955:20). In addition, a true polish is produced on edges of sickles and hoe blades used primarily for cutting certain grasses containing hydrated, noncrystalline opal (Witthoft 1967). This "corn gloss" or "sickle gloss" is produced by the surface frictional flow and mechanical polishing by a softer substance (opal) working on a harder substance (chert) (Ibid.). This type of gloss is restricted in space and time to agricultural and horticultural societies, and on the artifacts themselves preferentially appears on the used edges. Thus close examination of the distribution of the gloss should serve to differentiate this from glossy surfaces produced by heat treatment.

This discussion has shown that, while there are many natural processes which can produce lustrous surfaces on chert artifacts, careful examination can lead to differentiation of the various causes of the superficially similar artifacts. In order to properly identify heat treatment in the archaeological record, the specific environmental context must be familiar to the investigator. Several of these natural surface alterations are produced in restricted environ-

mental zones; hence the archaeologist must know the potential range of natural processes acting upon the artifactual material. On individual artifacts, examination with the binocular microscope may often distinguish between a surface mechanically abraded and one lustrous from heat. Furthermore, these natural processes can be most reliably distinguished from heat treatment by the fact that the apparent polish or gloss is a surface phenomenon, and a recent break will disclose the true character of the stone. Heat treatment, on the other hand, produces a luster only on surfaces flaked after heating. It is important therefore to be informed of the natural phenomena which may produce artifacts similar in appearance to heat altered lithics, in order to be able to use the relevant criterial to distinguish the end results of the various processes.

The problem of distinguishing natural from intentional heat treatment is two-pronged. First the analyst must be able to differentiate natural heat alteration from heating by humans. Second, having identified the human element, the analyst must be able to distinguish between chert altered as a spurious result of an unrelated process and used without selection for the changed properties, from chert altered intentionally to improve its quality. The problems inherent in segregating intentional thermal alteration are major, because the visual properties usually used as criteria are not sensitive to the distinction between accidental and intentional heat treatment.

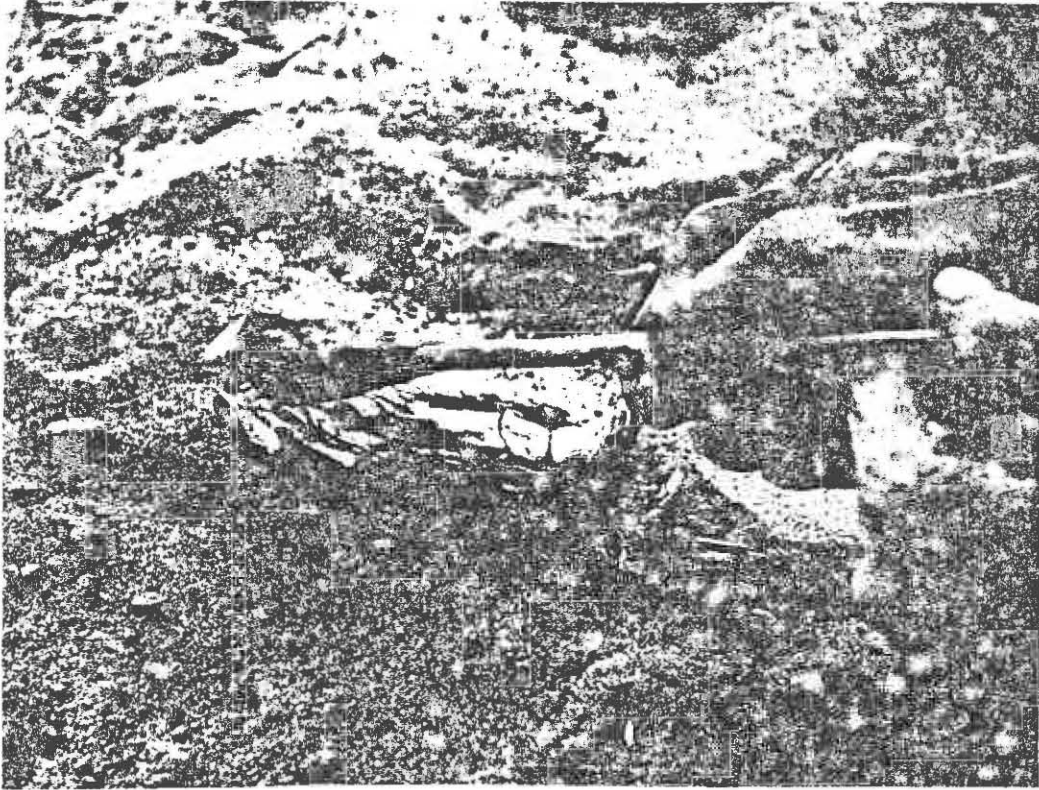
Much of the literature on this problem has dealt with identifying potential natural and accidental causes of heat alteration. Several accidental reasons for the presence of heated artifacts are due to heating by campfires, e.g., a tool falling into the fire or being left too close to the fire, the use of a spear to cook meat over the fire, the practice of heating resin over a fire to

haft tools (see Figure 5), or of situating the campfire over deposits containing lithic debris altered, then, by the proximity of the heat (Painter 1978:24-25). Alternately, small surface flakes can potentially be altered by natural fires, e.g., grassfires or brush fires (Anderson 1979:227). The significance of these various factors is not to be underestimated. It is fairly common to find burned lithic debris and fire-cracked rock in the vicinity of hearth features, making differentiation of specific heat treatment structures even more problematic. Brushfires or grassfires do not usually leave such localized deposits and thus can alter expanses of surface deposits if these pieces are small and thin and the fire intense. In particular, intentional heat treatment has been difficult to document in Mesoamerica due to the widespread and ancient practice of slash-and-burn agriculture. Surface collections at a chert workshop area at the site of Colha, Belize have revealed many artifacts and debitage which have been fire cracked or spalled; in one analysis of twenty-two "orange peel" flakes (from the initial manufacture of adze tools) 40% of the sample showed signs of heat damage or alteration. The heat alteration at this site is attributed to the yearly slash-and-burn cycles, still practiced today (Wilk 1976:153; Shafer 1976:23-26).

Finally, one postulated cause of unintentional thermal alteration is the process of quarrying stone (Gregg & Grybush 1976:191-192). Many of the early ethnographic reports of heat treatment describe the use of fire in assisting the breaking apart of large blocks of stone into smaller pieces (Schumacher (1877) 1960:304; Goldschmidt 1951:419; Powers 1877:104; Heizer & Treganza (1940) 1960:302; Lehman 1927 in Wallace & Hoebel 1952:105; Elkin 1948:110). These may be descriptions of a use of heat to fracture stone in quarrying or primary reduction, or it may be that these reports are confusing the heat treatment of large blocks of material with the use of heat in the quarrying process. More

Figure 5

Australian Aborigine hafting an adze-flake by heating resin on end of spearthrower over a burning piece of wood. (after Gould et al 1971:161)



explicit descriptions of the use of fire for quarrying come from the archaeological examination of quarry sites. Describing chert procurement in the Flint Ridge area of Ohio, Fowke (1895:201) details the procedure used to obtain buried and unweathered bedded chert:

After the earth had been stripped off over an area as large as was desired to work, a fire was kindled and kept burning until the flint was heated to some depth. Water was then thrown on, which shattered the stone. The fragments being cast aside the process was repeated, if necessary, until the pit thus formed had penetrated the underlying stratum. Clay was plastered on the upper portion of the flint to protect it from the heat, and a fire made against the bottom of the ledge, producing a cavity here and leaving the upper portion projecting. This was broken off with heavy boulders, and reduced by the same means.

A related account is offered by Mercer (1893:2) in the investigations of prehistoric jasper quarries in the Lehigh Hills of Pennsylvania; large pits had been dug into the underlying jasper deposits, some with charcoal found in the bottom. Here it is suggested that fire was not used in mining, but in breaking apart large jasper nodules or in clearing brush for the collection of near surface nodules (Mercer 1893:2). Skinner (1957:39,41) describes two quarry sites in Oklahoma, one with Peoria flint, the other for quarrying Kay County flint. The Peoria flint quarries are evidenced by large circular pits, partially filled with workshop debris; habitation/workshop areas are suggested by the "numerous circular clusters of chert with fire depressions in the center..." The other quarry operations are marked by shallow pits dug into the hillsides to extract nodules of Kay County flint; at this quarry area some of the artifacts made of this material show red coloration presumably due to heat alteration. These descriptions are problematic in that the effects of heat may be the result of the use of heat in the mining of the raw material; another likely possibility is the intentional alteration of the material at the quarry/work-

shop prior to reduction and manufacture into stone tools.

The use of fire in quarrying and primary reduction of siliceous material may alter the properties of the stone in such a way as to be indistinguishable from chert heated intentionally prior to manufacture. Visual criteria may not distinguish the two separate processes due to the similarity of the end-products. Manufacture of stone tools from material altered during quarrying is accidental heat treatment, because the artifacts produced were not heated for the intentional selection of the changed physical properties; here the heat altered properties are a by-product of the quarrying technique.

The inadequacy of the visual criteria for detecting heat treatment has led to the quest for a reliable, scientific, and absolute method of detecting heat alteration in siliceous stone. One result of this has been the development of thermoluminescence analysis of burned stone. Thermoluminescent dating of ceramics has increased in reliability and sophistication in recent years. A theoretically similar technique can be used to date burned stone in archaeological deposits. Stone which has been heated to 400° C. releases trapped electrons from the lattice of a naturally irradiated material in a thermoluminescent glow; at this point the radiation built up from the time of the geological formation of the stone is released and the "radiation clock reset" (Rowlett, Mandeville & Zeller 1974:37). Assuming that the stone has been heated prehistorically sufficiently to erase the geological TL, the date at which the stone was heated prehistorically can be calculated by measuring the thermoluminescence given off when heated in the lab (Wintle & Aitken 1977:111). The archaeologically acquired TL comes from several sources, mainly from radioactive trace elements within the stone itself, and from the depositional environment (Wintle & Aitken 1977:122). Thus to calculate a date, the radiations from the deposits must be measured as well.



Although theoretically an effective dating method, sources of potential error exist which have yet to be thoroughly controlled. Since chert receives radiation from the environment, samples used for dating must be stored in darkness; prolonged exposure to sunlight will skew the results of thermoluminescent analysis (Wintle & Aitken 1977:113). The potential error introduced by the exposure of specimens lying on the ancient surface prior to burial by additional cultural debris is unknown.

The main applicability of thermoluminescence analysis at the present time is in the detection of archaeological heat treatment. The basis for this method of identifying prehistoric heating of stone lies in the knowledge that a tool which has not been heated will have a relatively high thermoluminescence because radiation has been stored since the time of geological formation, whereas a heated tool will have a lower TL due to the release of radiation at the time of heating (Rowlett, Mandeville & Zeller 1974:39). In analyses of this kind it is also necessary to measure the background radiation of the depositional environment; thus the method is unreliable when used with isolated artifacts. Confidence may be placed in results if unheated chert from the same context is used for comparison. Ideally, the method would be used to compare TL of a group of artifacts from the same depositional stratum in order to segregate the heated from the nonheated artifacts. Practical considerations of cost limit the usefulness of this detection method to small samples. More significantly, however, thermoluminescence analysis cannot distinguish between accidental and intentional heat treatment (Anderson 1979:224).

It appears, therefore, that the usual criteria for evaluating heat treatment, i.e., color change and luster change, as well as the more scientific method of thermoluminescence, are inadequate for the differentiation between accidental and intentional heat treatment. There is, however, one criterion which can assist in the analysis of intentional heat treatment. Luster changes

in a heated stone are only detectable upon subsequent flaking of the surface; heat treated material retains its dull surface luster until flake removal. Detached flakes will show a glossy inner surface and a dull exterior if they are secondary flakes removed from a heat treated preform, and thus can indicate the stage in the reduction sequence at which heating was performed (Collins and Fenwick 1974:137). Collins (1973:462) writes that the only confident inferences of intentional heat treatment are those based on artifacts which exhibit "evidence for the following sequence of manufacturing steps: (1) initial shaping, (2) heat treating, and (3) trimming." This evidence on an artifact is in the form of patterned flake scars. Dull flake scars result from the initial reduction whereas glossy flake scars indicate retouch after heat treatment. Thus an artifact with contrasting dull and lustrous flake scars indicates intentional heat treatment at the unfinished preform stage (Bordes 1969; Mandeville 1973:183-185; Crabtree & Butler 1964:3; Klippel 1972:17-18).

In addition to the presence of contiguous contrasting flake scars on individual intentionally heated artifacts, Anderson (1979:228) has delineated several possible tests for the hypothesis that heat altered chert is accidental within the context of the assemblage;

- (a) Infrequent occurrence (low incidence) of intentional thermal alteration in lithic assemblages;
- (b) random distribution of intentional thermal alteration among finished chert artifacts;
- and (c) association of intentionally thermally altered artifacts with fire damaged cherts.

It must be emphasized that reliable determination of intentional heat treatment is best done within the context of the assemblage as a whole. When looking at patterns in the distribution of heat treatment among different artifact and debitage types, and taking into consideration related factors such as methods of lithic resource procurement and possible post-depositional

disturbances, a combination of factors can be weighed and heat treatment interpreted in the specific cultural context.

The most reliable detection of heat treatment in a lithic assemblage is that based on a comparative method. Controlled heating experiments should be performed using the local source materials, and the range of behavior of the experimentally heated chert compared with the variability seen in the specific assemblage. Anderson (1979:224) cautions that "statements made about thermal alteration without reference to experiment should be viewed, at best, as untested hypotheses." Because each siliceous material reacts individually to heat treatment, comparisons against experimentally heated material may use the relative and visual criteria such as luster change, color change, and flake scar characteristics with more confidence. Some sources of siliceous raw material will display more variability upon heating than others. In an experimental heating of twenty-three samples of Flint Ridge material, Patterson (1979c:33) found that while nine samples showed both a luster and color change, eight displayed only the luster change, five only changed in color, and one did not change at all in surface appearance. The variable nature of the results indicates that the absence of certain changes does not always mean the material has not been heated.

The comparative method additionally allows for the experimental replication of chipped tool forms from both heated and nonheated raw material. The investigator can thus get firsthand impressions of the workability and flaking characteristics of the natural chert, and discern any improvements in the degree of control, ease of knapping, types of flakes produced, and range of manufacture methods and finished forms which the heated material allows. Analysis of the debitage removed during experimental biface replication may provide a model for the types of debris to be expected when heat treatment is performed at a

given stage in the reduction sequence. Recognition of heat treatment from the debitage at a site may present particular problems, as Collins (1973:464) demonstrates through the analysis of chipping debris from a single biface replication experiment:

The number of flakes recognizable as being heated (34) out of a total of 198 flakes suggests that archaeologically the practice of heating cherts may not be represented by a very high percentage of clearly recognizable flakes. In the present specimen, 136 flakes were removed prior to heating, and, of course, do not show evidence of the practice. After the specimen was heated, a total of 62 flakes were removed, but only 34 of these exhibit on a single specimen the contrasts in lustre which are discernable by their proximity. The remainder of those removed after heating show a high lustre on all surfaces and would be perceived as heated only under ideal conditions.

It is this type of experimentation which can indicate the types of data which need to be sought in the archaeological record. Familiarity with the reactions of a particular source material to the heat treatment process may lead to hypotheses testable by further archaeological investigation.

## Part Four

### Detection and Interpretation of the Process of Heat Treatment

Heat treatment is known to be a widespread practice in the prehistoric stone-using cultures. However, documentation comes primarily from the artifacts themselves, i.e., the finished products of the process. In order to learn more about the technological and behavioral aspects of this practice, it becomes necessary to reconstruct the process of heat treatment itself, that is, how the heating was accomplished, and where it was done. The evidence may be gleaned from ethnographic descriptions of the process and from heat treating features in the archaeological record.

A parallel problem exists in the study of prehistoric metallurgy. It is not enough to examine the finished artifacts, although these reveal abundant information about the technology through the metallographic study of manufacture methods. However, in reconstructing the technology of metals, recourse is made to evidence of the process prior to the finished product. Thus, the student of metallurgy goes into the field to find the mines and slag heaps, the smelting furnaces and the workshops. Because of the nature of the archaeological record, these are frequently not preserved; artifacts are much more common. But the limited evidence available is valuable in that it allows the archaeologist to "observe" the technological process rather than inferring it from the finished product.

Similarly, in the study of heat treatment, we need to find the spatial correlates of the heating process, i.e., preserved features or structures which were used to heat chert prior to manufacture. From the structures, possible

methods used in heating are suggested, along with information about the degree of control over the process. Spatial distribution can indicate where within the site heating was done, and the locale of this in relation to the location of cooking and flintknapping activities; on an intersite level, it may be possible to discern whether heat treating took place at different types of sites, such as at the quarry, the workshop, or the home base. By investigating the physical and spatial correlates of the heat treatment process, we can get at the behavioral aspects of the technology as well as be able to more clearly interpret the evidence seen on artifacts.

In order for successful heat treatment to result, heating must be controlled and the temperature changes gradual. Insufficient heat will not alter the flaking character of the stone, although it may change the color. Too rapid a rise in temperature will cause heat damage and fracture. The specifics of heating temperature, duration of heating, and temperature tolerance vary according to the individual stone type. Experimental replicative studies have indicated that insulation of the chert by sand or dirt aids in regularizing heat distribution and protection from heat damage. In addition it appears that small thin pieces heat more evenly than large ones and are thus less susceptible to over-heating and explosion.

These findings of experimental heat treatment studies may be used as a base for an examination of heating methods and structures as described in the ethnographic and archaeological literature. Patterns discerned in the initial recovery of data may then be formulated into a coherent set of hypotheses to be tested by further excavation and analysis. This procedure is significant because not knowing what indicators to look for to distinguish a heat treatment activity area leads to the lumping of functionally discrete features into one general category (e.g. fire pit). Recognition of heat treatment features

then allows for interpretations of the process of heating.

In order to discover heat treatment methods employed aboriginally, I examined the ethnographic literature (see also Hester 1972). In general, the reports are scant and do not describe the heating process in any detail. Many sources describe methods of heat treatment which when attempted experimentally, failed to produce a desirable result (Mandeville 1973:179). The most popular myth in this regard is the notion that by dripping tiny drops of cold water onto hot chert, small flakes or potlids will be detached, presumably by the rapid local difference in surface temperature, and permit the shaping of a tool (Nagle 1914:140; Miller 1897:207; Elkin 1948:110; Lehmann 1927 in Wallace & Hoebel 1952:105). Variant accounts describing the use of fire in the manufacture of stone tools tell of chipping with heated hammerstones (Webster 1889: 602) or the working of siliceous materials while still hot (Robinson 1938:208). The profusion of these apparently faulty accounts has been ascribed to (a) second-hand reports of observations; (b) confusion, brevity or inconsistency in the reporting of informants' descriptions; or (c) faulty reporting influenced by the preponderance of the tale of the fire-and-water knapping technique in the popular literature of the late nineteenth century (Mandeville 1973).

There are, however, more reliable or feasible ethnographic reports indicating aboriginal heat treatment practices. In an account of the Andaman Islanders in the Bay of Bengal, Man (1883:379-81) describes the manufacture of quartz or chalcedony flakes used in scarifying and shaving by placing the stone on the fire, heating, cooling slowly, and then knapping small sharp flakes by percussion. Maler (1901:36-37) indicates that the Lacandon Indians of Mexico occasionally heat flint in order to facilitate "cleaving into thin layers" or blades which are finished by indirect percussion and pressure re-touch. The Viard or Wiyot Indians of California manufacture long thin arrow-

points by heating stone in a fire, slowly cooling it, and working by percussion and pressure techniques (Powers 1877:104). Schumacher (1877 in 1960:304-306) mentions heat treatment in the manufacture of tools which are finished by pressure flaking, with the flakes often traveling to the middle of the tool, among the Klamath River Yurok Indians of California. In an ethnography of the Surprise Valley Paiute in northeastern California, an informant recalls watching arrowpoints being made by pressure flaking obsidian which had been "warmed . . . on the coals" then broken into small pieces (Kelly 1932:141). Goldschmidt (1951:419), in his study of the Nomlaki in central California, writes that "flint nodules were broken into workable smaller pieces by means of slow, even heating. . . the resulting flakes were then heated by contact with hot stones and chipped."

There are only a few ethnographies which describe the heating process more specifically than as "warming over the fire." Yet these few hint at an increased control over the heating and perhaps more successful heat treatment. The Reese River Shoshoni of central Nevada placed flint under fire ashes for five nights prior to flaking, while the Shoshoni in the Snake River area of eastern Idaho roasted flint in the ground (Steward 1941 in Hester 1972:63). Grinnell (1926:147) describes the method of manufacturing obsidian and chalcedony tools among northern Plains Indians:

Each holds between his knees a block of stone, from which, by light sharp blows of a small stone hammer, he is chipping off triangular flakes of flint for making arrowheads. . . Each of these blocks has been sweated by being buried in wet earth, over which a fire has been built, the object of this treatment being to bring to light all the cracks and checks in the stone, so that no unnecessary labor need be performed on a piece too badly cracked to be profitably worked.

In another source, Sollberger "recalls hearing from Pete Gregory of the Univer-



sity of Northwestern Louisiana that historic Indians in the Catahoula Lake area of Louisiana had a ceremony to steam siltstone before knapping. . . This was done by building a fire over flint buried in wet earth" (Patterson & Sollberger 1979:51). These reports are intriguing because in these cases there is evidence of some means of protective insulation of the stone from the direct action of the fire. Wet earth, pit burial, or ashes all serve to protect the stone and permit gradual, more controlled heating.

Thus from the ethnographic record, we see several possible methods of heating siliceous stone. The stone may have been heated directly in the fire, although to be successful this would require a tough raw material with wide tolerance for temperature change. An alternate method would be placing the stone among the coals of the fire, perhaps insulated with surrounding ash. An increase in the control and sophistication of the process of heating is reflected in the accounts of burying raw material in a pit beneath the fire or building a fire over chert protected with wet earth. Perhaps further examination of the ethnographic record will provide other possibilities for aboriginal heat treating methods.

Turning now to the archaeological record, I would like to begin by postulating some archaeological correlates of these ethnographically documented heat treatment methods. What kinds of evidence may be expected upon excavation of these heat treating features which distinguishes them from other types of features seen in cultural deposits? First, direct heating of raw material over an open fire not only increases chances of heat damage by rapid temperature change, but also might not be reflected archaeologically by a specific structure. Likewise, the method of placing the stone among the ashes and coals of the fire does not seem to necessitate the construction of a specific heat treatment feature. In either situation, the regular cooking and heating hearth would

suffice. In the excavation of such areas of the site, the archaeologist should examine hearth features closely; remains of heat treatment activities may be only an unusual amount of fire-damaged local raw material and perhaps heat altered chipping debris. In the cases where stone was heated in pits covered with the fire, or under wet earth and a fire, specific heat treatment features may be distinct from the regular cooking hearths at the site. Here the indications of heat treatment activity may be seen in pit features, areas of burned soil, ash lenses, as well as fire damaged debris both in and around the pit and heat treated manufacturing debitage. A point to remember is that quantities of fire-cracked rock may indicate the practice of "stone-boiling" or cooking and roasting food with heated rocks (Lorrain 1973; House & Smith 1975). Thus in determining the presence of heat treatment features it is best to look at several factors in the specific site and cultural context. Features must be examined with the goal of segregating distinct functions, and the lithic assemblage should be analyzed keeping indicators of heat treatment in mind.

I would now like to describe the few examples from the archaeological literature of features interpreted as heat treatment stations. Following this I will proceed to the more enigmatic possibilities, and conclude with a discussion of two potential areas to be examined more closely in light of this discussion of heat treatment structures.

During construction in the Tuttle Creek Reservoir spillway near the Kansas-Missouri border, flakes of the local chert were discovered eroding out of a bank. When clearing by trowel, Shippee (1963:271) discovered

a cache of flint flakes and cores capped by three limestone boulders, spread evenly over a bed of ashes which remained from a fire of considerable intensity. The layer of flint was four inches thick and the ash averaged the same. Fragments of a large scapula and a legbone were scattered in the flint layer. In addition, several teeth of a dog or coyote were recovered; however, no artifacts were found.

Although Shippee did not find any evidence from the flint itself that the stone had been heated, the context indicates that this is indeed a heat treatment structure. It may be inferred that the chert was placed over combustible material in a pit and covered with rocks and dirt, yet not recovered after heating and cooling were completed.

A similar find was described from Fishkill, New York near the Hudson River. Shepard (1877:308) describes the discovery of a cache of arrowpoints uncovered by a workman engaged in landfill:

While employed in digging, his spade brought up a number of arrowpoints. He described them to be nicely piled side by side, edgewise, in two or three rows. There were perhaps two or three hundred in all. On each side and on top were some charred logs and sticks, that seemed to be the remains of an old fire. They were 10 or 15 inches below the surface of the pond ponded water on the bog hole in which the cache was located. They are of a blue jaspery flint, and seem to be in an unfinished condition. . . .

Although Shepard does not recognize the material as local to the area, from the description of the context of the discovery in a wet organic-rich soil, the blue color of the material may be the result of patination. The interpretation of this feature by Shepard is that here some aboriginal inhabitants cached or hid the points, covering the traces by building a fire over the area. However, I think an explanation providing a better fit to the data is that this feature is a heat treatment structure in which several hundred point preforms were heated prior to final manufacture and finishing by pressure flaking. In this case, like the previous description, recognition of the function of the feature is based primarily on the coterminous fire remains and raw material. These may be special preservation circumstances, found only in cases where the structure was left with the chert intact after heating rather than retrieved for manufacture into tools.

Another probable heat treatment feature is described by Sollberger and Hester (1973:182-3), located at a large quarry site in central Texas where both tabular and nodular chert is exposed and apparently was quarried by aboriginal people. In the report, Sollberger writes:

On the hilltop above the ledge exposure there is a fire-darkened area, circular in shape and 12 to 14 feet in maximum diameter. Within the circle are large numbers of flakes, some of which are visible on the surface. All appear to have been obtained from the ledge or nodule exposure. Outside of the fire-darkened area, there are large amounts of workshop debris. However, these workshop flakes are quite different from those found within the fire-darkened area. The flakes from that area are of various shades of pink and red, whereas the flakes from the workshop debris still retain the blue-gray color of the ledge/nodule materials.

In addition, Sollberger points out that there is an occupation site, located across the river from the quarry, where the abundant chipping debris exhibits predominantly the pink-red hue and lustrous surface indicative of heat treatment. A raw material procurement and reduction sequence can be hypothesized from these data. It seems likely that the raw material was quarried at the outcrops, shipped into smaller "packages" and then heat treated near the quarry area; after transportation across the river to the home base, the heat treated flakes and preforms could be retouched into a variety of tool forms. Repeated use of a particular area for heat treatment would presumably leave a large fire-darkened area with heated flakes within, and primary reduction waste without.

This latter example in particular illustrates the place of heat treatment in the local lithic industry. The next two cases do not show the physical traces so vividly. In these reports, the interpretation of heat treatment areas is based not only on the preservation of firepits, but is inferred from the spatially restricted distribution of heat altered chipping debris and fire-

cracked rock.

The chipped stone industry of the Paleo-Indian occupation at the Holcombe Beach site (Macomb County, Michigan) is composed of 96% Bayport chert, from a limestone formation in the lower peninsula area. This chert is in the form of small nodules, frequently with fossil inclusions, which range from white to gray in color; the dark gray variety (29% of the debitage) shows indications of heat treatment (Fitting et al 1966:19-25). In the debitage analysis, it is noted that in the category of "block fracture flakes," about half the specimens are of dark gray Bayport chert. It is suggested that these block fracture flakes are products of heat fracture rather than knapping. When comparing the distribution of dark gray chert and block fracture flakes with the distribution of fire-cracked granitic rock, there is a significant correlation. This association is strengthened by the experimental heat treatment results: Bayport chert darkens approximately one Munsell shade in all varieties when heated (Fitting et al 1966:36). In addition, Fitting found a higher percentage of preforms and finished bifacial artifacts made from dark gray Bayport chert than would be expected given the frequencies of the chert varieties (Ibid.:62).

Fitting interprets this evidence as suggesting that preforms were "placed in the sand near a fire area and heated before they were finished into bifacial tools"; the broken preforms and block fracture flakes indicate that control over this process was low (1966:62). This heat treating is thought to have occurred at one central feature where the majority of the block fracture flakes, as well as preforms, are clustered. At this central area of the site, it is suggested that the preparation and heating of preforms took place, communally because the individual never knew how many pieces would be destroyed in the heating process; finishing and resharpening of the heat treated material took place at the peripheral family locales (Fitting et al 1966:70-74).

The Debert site, in central Nova Scotia, is another Paleo-Indian occupation; here eleven separate areas were excavated and analyzed for lithic source material, artifact type and debitage proportions, and features found within (MacDonald 1968). One section in particular has anomalous characteristics which have been interpreted as indicating heat treatment activity. Section D contained a large circular area of lithic debris, in the center of which was a series of small pits, once interconnected (MacDonald 1968:36 and Fig. 7). The area of these pits is larger than the feature area of any other section, yet the radiocarbon dates from charcoal taken from individual pits in the feature had only about a hundred years' deviation from the average date (Ibid:38). A high concentration of waste flakes was found between the individual pits of the feature; 25% of the total recovered debitage came from Section D (Ibid:28 and Table 2). MacDonald describes the feature, numbered 7 (1968:38):

The pits surrounding 7f [the largest] were little more than basins in the till, containing charcoal and waste flakes (many of which were fire spalled) and partially covered by cappings of till. At first it appeared that the till caps originated in post-occupation tree-throw, but since no pits, other than those filled with charcoal, were found from which the capping material could have originated, it is more likely that the cap represents the pit fill used to cover the pit after it was filled with charcoal and chips. Intrusions through the cap probably represent openings made to remove whatever material was being heated in the hearths.

MacDonald's interpretation of Feature 7 as a heat treatment area seems justified by several lines of evidence. First, the pits contain both charcoal and heat altered flakes. Second, the high concentration of waste flakes in Section D may result from knapping in the area either before or after heat treatment; the ratio of waste flakes to artifacts for this section was 30:1, much higher than in other sections, indicating manufacture of tools as the primary activity in this section (MacDonald 1968:38). Third, bifaces and unfinished points or

reading it occurred to me that there are two feature phenomena which have remained functionally enigmatic despite several decades of study. I would like to suggest that a function as a heat treatment station may contribute to the interpretations of at least some examples of these phenomena. Specifically, I am speaking of the numerous reports in the last hundred years of "caches" of bifacial points or preforms found in east-central United States; the term "cache" as a generic term for these deposits masks a great deal of functional variation which may be differentiated if the depositional context is examined thoroughly. Secondly, there is the structural phenomenon collectively termed "burned rock middens" with examples from southwest Texas and similar features in parts of the British Isles. While not attributing primary function and formation of these mounds to heat treatment, I am suggesting that interpretation of these might benefit from an analysis of possible heat treatment at these sites.

Deposits of stone implements, numbering from only a few to several thousand, have been found in concentrations in the states of Ohio and Illinois; these "caches" of stone tools are usually attributed to the Adena or later Hopewell of this region. Ellis (1940:111) collected some sixty-three reports of "unused circular or ovoid, flat, roughly-chipped blanks of flint buried in what may have been termed 'ceremonial' or 'storage' caches." Likewise, Snyder (1877,1893) distinguishes two kinds of caches--small deposits of either used or unfinished flints, and large deposits of flints bordering on monumental quantities--to which he proposes different functions or reasons for burial. The first type is found throughout the Mississippi Valley in concentrations buried relatively shallow in the ground and containing a convenient number of individual specimens for carrying (Snyder 1893:184). The new or unused bifaces are suggested to be the stores of traders, placed in the ground for storage and "hidden away until again wanted, or for safe-keeping during the temporary absence

of the owner" (Snyder 1877:435). Unfinished preforms were perhaps stored in the ground to preserve the flint in its fresh moist newly-quarried condition (Snyder 1893:183-4; see also Patterson & Sollberger 1979). The small deposits of finished bifaces showing signs of use may have been stored in the ground after utilization in a specific activity, such as canoe building on the bank of a river (Snyder 1893:184).

The second type of cache deposit is that of large numbers of finished chert disks or bifaces found in mound deposits, often associated with other material goods, skeletal material, and ash or fire remains in what have been referred to as "sacrificial mounds." Snyder (1877:436) offers a composite sketch of this type of cache:

The "altars" of burnt clay; the votive offerings, through fire, of their choicest works in stone, copper, mica, and shell, doubtless together with many articles of less durable materials which were consumed by the intensive heat; the cremation of human bodies, the heaping of earth upon the glowing mass; and the introduction of strata of sand in the enveloping tumulus, with the outward covering of coarse gravel, together constitute a record wonderful and unparalleled. . . We have here no stores of hidden goods to be withdrawn at pleasure, for use or traffic, but a deposit of objects made in accordance with some superstitious rite or religious notion, and designed to remain there undisturbed to the end of time.

Deposits of flint bifaces in these circumstances are clearly different in kind from the small deposits of implements buried in more culturally isolated situations. Perino (1971a:99) found in excavations of nine Hopewell mounds in Pike County, Illinois, that many of the tombs contained "large, new, polyhedral flint cores, and all showed evidence of having been fired or heat treated" based on the red coloration of the Burlington chert which naturally outcrops as white in color; also found in Illinois grave caches were "blade knapper kits" containing heat treated cores and detached blades, antler batons, and core abraders (Perino 1971b in Morse 1974:15). Crabtree likewise notes that



the Flint Ridge material used by the Hopewell of central Ohio is often heat treated in the manufacture of the finely flaked implements. (Crabtree & Butler 1964:1). Although it is reasonable to hypothesize that heat treatment was part of the technological process in the manufacture of these ceremonial cache blades, I do not think that the depositional context itself--within mounds with remains of fire--is indicative of a heat treatment structure. Rather, I am suggesting that a portion of the smaller caches were the heat treatment stations, instead of being exclusively used in storage.

A quick survey of the Ohio Archaeologist produced twelve reports of small caches of flint bifaces or preforms (see Bibliography, Bush 1979), which were examined to see if there was a correlation between this type of cache and evidence indicative of a heat treatment function. I looked for signs of ash or fire remains, pit outlines in the soil, and evidence of heating on the artifacts themselves in the descriptions of these caches. Unfortunately, nine out of the twelve reports described caches either "discovered" by the plow or in otherwise uncontrolled excavation, and in these cases there was little data other than descriptions of the artifacts. Since the surrounding soil and depositional context was not observed in these uncontrolled excavations, it is impossible to discern functions of these caches. Of the remaining reports, one described the looting of a burial associated with a cache of Flint Ridge artifacts, all found below a charcoal layer; another makes no reference to excavation but mentions that the artifacts themselves, seven laurel leaf bifaces made from the same type of flint, appear to have been heat treated based on the coloration (Kelley 1978:18). Finally, one report describes the excavation by the Historical Society of a cache uncovered during the plowing of a field (Fifer 1962). The cache itself contained thirty-five ovate or square based bifaces made from multicolored Flint Ridge material, some of

which were scattered outside the central area probably by the plow. In this report Fifer (1962:94) made some observations on the depositional context:

A shallow pit which is believed to have contained the entire cache before cultivation, was located in an area of several surface finds . . . the bottom of the pit, located below the range of the plow, measured 6 1/4" in diameter and 3 1/4" in depth. At the bottom was a layer of charred wood measuring 1 3/4" in depth, covered by another layer of crushed sandstone measuring 1 1/2" in depth.

This context as described is similar to the heat treatment features described earlier in this section, with the charcoal, the insulating sand layer, the pit demarcation, and the remaining artifacts within the pit. This I would interpret as functioning as a heat treatment structure.

Because so many of the caches reported in the literature are found accidentally and no detailed observations made on the context of burial, it is often not possible to interpret the reasons for the concentration of such artifacts. More careful description accompanies those caches found in the excavation of mounds; here, however, the context is different, and these are probably correctly interpreted as caches of a ritual nature. The dramatic finds of large numbers of implements buried in mounds has led to the term "cache" taking on connotations of ceremonial or ritual deposition. This is deceptive when used to describe the small scale type of artifact concentration. In the latter case, the distinct functions of storage, offering, and as I have suggested heat treatment, may be represented. The lumping of inferred functions into one term like "cache" is detrimental in that too often the specific reason for the deposition of the concentration of artifacts is at least tacitly assumed to be ritual, rather than being determined for each individual case on the basis of the association and context of the deposit.

Quite a different phenomenon are the large scale structures termed "burned rock middens" which are found in parts of Britain and Texas. In both areas,

these structures are large accumulations of fist-sized limestone, sandstone, or less commonly chert rocks and admixed dirt and ash, all showing evidence of thorough burning (Wilson 1930:59; Huxtable et al 1976:5). The piles of burnt rock are usually fairly low in profile but range in diameter from several to twenty meters (Ibid.). Diagnostic artifacts are conspicuously absent from most burned rock middens. Excavations of these structures, however, reveals varying featural contents. In Texas, the La Jita site consisted of Middle Archaic deposits on the terrace with disturbed hearths and the majority of the charcoal, calcined bone, and burnt flakes, while the mound itself contained burned rock and soil but little cultural debris (Hester 1971:124). The Indian Creek site revealed burned limestone rubble, stone slabs, tools and debitage, and features indicative of cooking hearths and small fire pits (Shiner & Shiner 1977:278). The evidence from Scotland, Ireland and northern Britain indicates that these burnt mounds frequently contain large trough structures, hearths, and sometimes stone-lined pits (Huxtable et al 1976; O'Kelly 1956).

The function of these large scale piles of burned rock is as yet enigmatic. Suggested reasons for the accumulations are: repeated usage of one area resulting in superimposed hearths; the disassembly of hearths in adjoining areas leading to the accumulation of refuse hearth debris and burned rock (Hester 1971:124); the remains of stone-lined pits where plant or root material was roasted (Wilson 1930:62); the repeated digging, using, and infilling of small pits used for cooking (Shiner & Shiner 1977:275); and the byproduct of a subsistence technique whereby meat was cooked in troughs by stone-boiling water (O'Kelly 1956:616). In general, then, the accumulation of such quantities of burned rock seems to stem from the use of stone to line hearths or from cooking practices involving heated rock as an intermediary heat source. The heating of rock, either intentionally or spuriously, would generate large quantities of

broken stone, discarded when the fragments were too small for use.

Although cooking practices seem to be the primary reason for the accumulation of these burned rock middens, it may be that the hearth areas and fire pits have a secondary function as heat treatment pits. At the Indian Creek site, although possibly functioning in heat treatment of lithic raw material, the evidence is at best suggestive or indirect, "because we could not tell if the flint had been deliberately placed in the fire" (Shiner & Shiner 1971:278). From the physical structure of a fire pit, both the roasting of root plants and siliceous raw material might be postulated; the physical similarity may well obfuscate the archaeological separation of distinct functions in the absence of material traces within the pit. Intensive investigation of these burned rock middens, therefore, may provide evidence for varying uses of fire within a specific cultural context. A range of discrete functions or activities may well be represented in what appears to be a homogeneous mass of fire-cracked rock.

Identifying the physical evidence of heat treatment in archaeological sites is the first step in analyzing the spatial distribution of this technological process. Questions are then posed such as where in the site heat treatment takes place, and at what types of sites heating was preferentially done. This type of spatial information aids in settlement pattern analysis and interpretations of the scheduling of activities within a regional seasonal round. This level of analysis has yet to be investigated in detail with respect to heat treatment. Ideally, heat treatment should be studied within the scope of regional site surveys and lithic procurement analyses. We are interested in finding out whether heating occurred at the quarry itself after primary decortication, at temporary workshops near the quarry, or if quarried "packages" or preforms were brought back to the home base to be heated. This type of

information on the local level may be interpreted from the presence and degree of heat treatment at different kinds of sites as based on both feature evidence and analysis of heat treatment among lithic debitage.

Several hypotheses may be offered pertaining to the question of where heat treatment was undertaken. From experimental heating studies, we know that effective heat treatment takes time. Gradual heating and cooling leading to successful treatment has been reported for different experiments as taking from twelve to forty-eight hours, with twenty-four hours most common. The duration of the process may vary according to the lithic raw material. Thus the time spent at the quarry site may determine whether heating is done there. Anderson (1979:231) suggests that heat treatment might be done at the quarry if the raw material is poor, i.e., enabling improved and successfully heated raw material transported with less waste, or if extraction of the stone is difficult, necessitating several days spent at the quarry site. It has also been suggested that the length of time required for heat treatment would lead to a preference for heating at the base camp, where occupation is more permanent than at a temporary camp or lithic extraction station (Fitting et al 1966: 111-113).

In addition to the temporal factor, the distance from habitation to quarry may influence where heat treatment occurs. Heat treatment may increase in incidence on all sites for a particular lithic material with the increasing distance from the source as a conservation measure (Anderson 1979:231). If the raw material is readily available locally, heat treatment might be done at the home base; in such a case even if the heating process results in damage, obtaining more raw material is relatively easy (Ibid.).

An examination of the archaeological data may provide some preliminary testing of these hypotheses, although few analyses have compared heat treatment

on an intersite level. Initial work has been done as part of the Cache River Basin survey in Arkansas (House 1975b,1977). Although many habitation sites are located in the valley, the raw material sources are limited to the upland gravel deposits on the ridges; a survey of upland sites was made directed towards lithic resource procurement data. At one upland site there was a high proportion of apparently heat altered chert, and many sites have quantities of fire-cracked rock, perhaps from thermal destruction during the heating process (House 1977:31). Heat treatment appears widespread at many sites' assemblages in the Cache River Basin, but experimental replication and quantification have yet to be done.

At Antelope Creek, Idaho, Crabtree notes that there is no evidence of heat treatment of the coarse jasper-agate at the quarry site while at a nearby campsite the identical raw material exhibits some heat treatment (Crabtree & Butler 1964:3). This seems to indicate heating at the home base rather than quarry site. Conversely, at the site in Texas discussed earlier, Sollberger describes a heat treatment feature at the quarry locale while across the river at the occupation site, the lithic material is predominantly heat altered (Sollberger & Hester 1973:182-183).

In the Holcombe Beach analysis, Fitting (et al 1966:111-113) compares the lithic assemblage of the Holcombe Beach site with several other Paleo-Indian sites in the area with less intensive temporary occupations. It is suggested that the presence of heat treatment at Holcombe Beach and its absence at the temporary campsites is due to the length of time needed for preform preparation and heat treatment.

Anderson (1979:235-6, Table 5) offers some data from fifty-six sites on the Coastal Plain of South Carolina and Georgia, to test the incidence of heat treatment at sites as a function of increasing distance from the raw material

source. Although there is a much lower frequency of heat treatment of bifaces at the quarry site than at sites a short distance away, there is little difference in the heat treatment frequency between sites 32-80 km from the quarry and sites more than 80 km away (Anderson 1979:236).

Finally, it may be advantageous to examine debitage at a site to see when in the reduction sequence heat treatment takes place; this may indicate whether raw material is brought to the habitation site for heating already reduced past the primary decortication stage. Hartley (1974:124-125) analyzed the debitage from the Von Elm site in Oklahoma, comparing heat treatment frequencies of decortication flakes versus secondary flakes for each of the four excavated areas. A trend is seen in that higher percentages of secondary flakes are heated than decortication flakes in all areas. In addition the relatively high incidence of unheated material (35-63%) suggests heating occurred at or near the site, on the assumption that if heat treatment occurred away from the site, most if not all debitage should be heat altered (Hartley 1974:125).

These archaeological examples of intersite heat treatment analysis are not conclusive. However, the preliminary attempts show the potential information about regional activity which can be gleaned from the spatial examination of the heat treatment process. Physical heat treatment structures are valuable kinds of evidence; features cannot be moved like artifacts are thus are in situ manifestations of behavior, which lend themselves to locational analyses. Identification of these features as heating structures from their physical context provides information on both heat treatment methods and spatial patterning within the site. Comparisons of heat treatment between sites, using both featural and artifactual evidence, allows the archaeologist to see the heat treatment process at the level of regional lithic resource procurement.

## Part Five

### Technological Interpretation of Heat Treatment

A lithic technology is a set of techniques of shaping and working stone, and knowledge of the properties and characteristics of the raw materials utilized. The set of techniques and knowledge constituting a technology enables a group to interact with and exploit its local environment. Through this cultural medium, natural materials are formed into tools which are used to work other substances and make other tools. Components of a lithic technological system are the nature and procurement of the raw material, the manufacture methods and sequence of reduction from raw material to finished tool, and the subsequent use and reuse of the tools produced. This ordering reflects the "life" of a tool, but in reality, each component influences and is influenced by the others. The type of raw material used has direct bearing on the range of manufacture methods and techniques used to work the stone, and with a wide variety of raw materials to choose from, the flintknapper picks a stone based on the intended form and function of the tool (Crabtree 1975:108). This inter-relatedness results in the complexity of the system from an analytical viewpoint. It is very difficult to isolate the effects of one component upon the finished product, the stone tool found on an archaeological site.

If it were possible, however, to segregate the most fundamental variable of a lithic technological system, it would be the raw material. Therefore, heat treatment of lithics has important consequences in the technology as it enables the stoneworker to intentionally alter properties of the raw material. John Rick (1978:54) mentions in comparing unaltered versus heat treated chert



that this is not merely comparison of a higher or lower quality lithic, but that "in a sense they are two different raw materials with different working qualities useful for different purposes." We have examined the physical changes which result from heating siliceous stone, and the physical evidence of the process itself. The question which now demands attention pertains to the behavioral or technological aspects of the process. Why was heat treatment employed in the manufacture and use of stone tools? What are the advantages and disadvantages conferred by the use of heat treated raw material? What are the causes of the variability seen in the distribution of this trait both within and between archaeological assemblages?

It must be assumed that when time and effort are spent in the heat treatment of lithic raw materials, the results are justified in some aspect of the manufacture or use of the tools produced. In a given cultural context, intentional heat treatment reflects selection for certain altered properties of the raw material. Assuming that the option of heat treatment is available to the prehistoric flintknapper, knowledge of these changes in physical properties allows us to predict where heat treatment would be expected in a lithic assemblage and under what circumstances the decision to heat treat raw material would be made. Once heated, the altered properties of the raw material have consequences in both the reduction of the stone and the use of the tool itself; the study of heat treatment bridges the multiple components of the lithic technology. Because of the difficulty in assessing which attributes of a finished tool are caused by the manufacture process and which are related to the function of the tool, it is clearer to break down the technology into its component stages and attempt to predict the effects of heat treatment on each stage. This may be done by means of a model. Using such a predictive model, we can postulate which variable is most important or relevant in a particular cultural

context.

Several explicit models have been offered to explain and predict the decision to heat treat raw material in lithic technologies. Although the formats vary, the relevant aspects of the models developed by Rick (1978:55) and Anderson (1979:227-231) pertain to improvements by heat treatment for the manufacture and functional performance of tools. In the interest of clear presentation, I will first briefly describe these alternate models, and then offer my own analysis of the situation, acknowledging my indebtedness to the two cited above.

John Rick (1978:55) presents a cost-benefit model for the decision to use heated or unaltered chert at the end of his thorough experimental study of heat treatment (see Figure 6). This model is based on a least-effort principle whereby the relative advantages and disadvantages of using a particular heat treated chert are weighed against the alternate raw material choices. In the heating process itself, both time and effort are expended, with variable results dependent on the control over the heating conditions and the tolerances of different cherts. Once the heated raw material has been obtained, there are critical advantages, as determined experimentally, of using a heat treated material in the manufacture of stone tools. The increase in ease of knapping and control over the flaking properties of the stone are valuable here. Turning to functional considerations, the thinner sharper edges and decreased edge durability of tools made of heated material have both benefits and disadvantages for tool performance. Rick emphasizes that "each tool type must be considered separately within the context of the model, since differing manufacturing processes and uses give the factors within the model considerably different values" (1978:56). The value of this model is the emphasis on the relative nature of heat treated chert as an improved raw material. From this we can see that heat treatment must be analyzed within the specific cultural context in order to assess the

| I<br>COSTS OF HEAT ALTERATION  | II<br>BENEFITS OF HEAT-TREATMENT<br>FOR STONE TOOL MANUFACTURE  | III<br>COSTS OF USING HEAT-TREATED<br>TOOLS   | IV<br>BENEFITS OF USING HEAT-<br>TREATED TOOLS  |
|--|---|---|---|
| <p>The total costs of heat treatment . . .</p> <p><i>Costs consisting of</i></p> <ol style="list-style-type: none"> <li>1. <i>Effort expended to procure alterable material.</i></li> <li>2. <i>Effort in gathering fuel for fire.</i></li> <li>3. <i>Effort of preparing heat-treatment facility.</i></li> </ol> <p>divided by . . .</p> <p>amount of chert surviving heat alteration . . .</p> <p><i>Survival of chert affected by</i></p> <ol style="list-style-type: none"> <li>1. <i>Knowledge of heating properties of different cherts.</i></li> <li>2. <i>Controlled application of heat</i></li> </ol> <p>gives:</p> <p>cost of heat treatment per unit of usable material.</p> | <ol style="list-style-type: none"> <li>1. Less energy expenditure to initiate fracture results in . . .             <ol style="list-style-type: none"> <li>a. <i>easier tool manufacture.</i></li> <li>b. <i>less failure in making tools.</i></li> </ol> </li> <li>2. Greater variety of forms possible because of improved fracture characteristics gives . . .             <ol style="list-style-type: none"> <li>a. <i>greater latitude for variety in thickness, length, and width.</i></li> <li>b. <i>potential for more acute edge angles on retouched tools.</i></li> </ol> </li> <li>3. Lower fracture strength results in . . .             <p><i>longer lifespan for antler manufacturing tools.</i></p> </li> </ol> | <p>Decreased durability of edge due to lower fracture strength.</p> <p>Disadvantage or cost of lower durability is determined by . . .</p> <ol style="list-style-type: none"> <li>1. <i>Tool function.</i></li> <li>2. <i>Length of time tool is to be used.</i></li> <li>3. <i>Cost of reworking worn or broken edge</i><br/>or</li> <li>4. <i>Cost of manufacturing a replacement tool.</i><br/>(3 and 4 are affected by Col. II.)</li> </ol> | <p>Increased sharpness of tool edge.</p> <p>Advantage or benefit of increased sharpness is determined by factors listed under Col. III.</p> |
| <p>For any given tool type . . .</p> <p>evaluation of the costs and benefits of heat treatment listed under the four columns above . . .</p> <p>permits an assessment of the relative advantage or disadvantage of using heat-treated material . . .</p> <p>which leads to:</p> <p><b>DECISION TO USE HEAT-TREATED OR UNALTERED CHERT</b></p>  |   |   |   |
| <p>PRECONDITIONS FOR THE MODEL</p> <ol style="list-style-type: none"> <li>1. Need for manufactured tool.</li> <li>2. Knowledge of heat treatment process and its consequences.</li> <li>3. Availability of chert suitable for heat treatment (local or traded).</li> </ol>   |   |   |   |

Figure 6  
A model for the decision to heat treat.  
(after Rick 1978:55)

viability of alternatives.

D.G. Anderson (1979:227-231) developed a model to explain why evidence of heat treatment might occur on an archaeological site, and proceeded then to subject the model to a partial test against some archaeological data (see Figure 7). Anderson (1979:227) reasons that:

Selection for thermal alteration will occur (assuming a basic knowledge of the process exists) where these controls [over the heating process] can be efficiently met and where raw materials with properties similar to those of altered chert are desired but are not readily available by other means.

Five reasons for intentional heat treatment are discussed, in addition to the presence of accidentally heated lithic materials at a site: alteration for specific appearance; improved raw material quality or workability; sharper cutting edges; soft hammer percussion or pressure flaking efficiency; and raw material conservation. These reasons for heat treatment are similar in import to the benefits for manufacture and/or tool performance which are posited by Rick. However, Anderson's model has direct value in that possible "test implications" or archaeological correlates are described for each reason. Anderson thus provides measures at the empirical level for the predictions at the conceptual level, an essential step which Rick does not offer.

I would like to now offer a model which partitions lithic technology into its component stages, and using predictions suggested by the physical effects of heating on siliceous stone, detail the choices available to the flintknapper. The pertinent properties of heat treated chert are in contrasting pairs: ease of knapping and increased brittleness; thinner flake edges and decreased edge durability. These physical effects of heating may influence any stage in the lithic technology. Here I will examine the following aspects of a chipped stone tool industry: nature of the local raw material; manufacture method and

## Figure 7

Model of when heat treatment may be expected  
to occur in archaeological assemblages.  
(from Anderson 1979:227-231)

### Reasons for Heat Treatment

### Possible Test Implications

- |   |   |
|---|---|
| 1. accident                                   | a. low incidence of intentional heat treatment in lithic assemblage,<br>b. random distribution of heat treatment among finished lithic artifacts,<br>c. association of intentionally heat treated artifacts with fire-damaged cherts.   |
| 2. specific appearance                        | a. differential status-linked distribution of heat treated and unaltered artifacts in same artifact categories,<br>b. high incidence of heat treatment in specific artifact categories without apparent selection for other advantages. |
| 3. improved quality                           | a. overall high incidence of heat treatment on cherts from specific sources regardless of artifact category.  |
| 4. sharp cutting edges                        | a. high incidence of heat treatment on cutting tools,<br>b. low incidence of heat treatment on heavy duty tools.  |
| 5. soft hammer or pressure flaking efficiency | a. higher incidence of heat treatment on artifacts with soft hammer or pressure flaking than on those made with hard hammer percussion,<br>b. higher incidence of heat treatment on debris from hard hammer percussion.                 |
| 6. raw material conservation                  | a. higher incidence of heat treatment with greater distance to sources, assuming no closer raw material sources.  |

reduction sequence; tool function; and tool reuse and recycling.

First, the nature of the raw material must be investigated. If the local source is of poor quality for knapping because it is too hard or tough for controlled flaking, the stone tool maker has two choices: (1) heat treat the local material to increase workability; or (2) obtain a higher quality material through trade or other means from a non-local source. Heat treatment may also be used to improve local source material when the raw material "packages" are small, as with river cobbles. Here, heating the stone enables manufacture of a larger tool than with unheated raw material, as controlled flaking means less waste during manufacture. A third problem with the local resource quality may be that the stone is weathered or riddled with internal flaws, cracks, or fossil inclusions. Although heat treatment does not "cure" badly weathered flint (Chapman 1975), the heating process may assist in revealing internal flaws in the material--the stone will break along these lines of weakness during heat treatment--and material surviving the heating will be less prone to failure during manufacture. Solving these problems with the local source material through heat treatment can be more efficient than exploiting a higher quality but more distant source. Heat treatment may also be employed as a raw material conservation measure. If the raw material source is some distance from the habitation site, the stone may be heat treated at the quarry in order to transport only high quality workable stone, with less waste. Alternately, the local poor quality source material may be heated to facilitate chipping of everyday tools, saving the high quality "exotic" stone for special or technically demanding tool types.

Secondly, in the area of tool manufacture, heat treating allows greater ease of fracture and thus improved "workability" of formerly tough materials, extending the range of raw materials which may profitably be worked by the stone

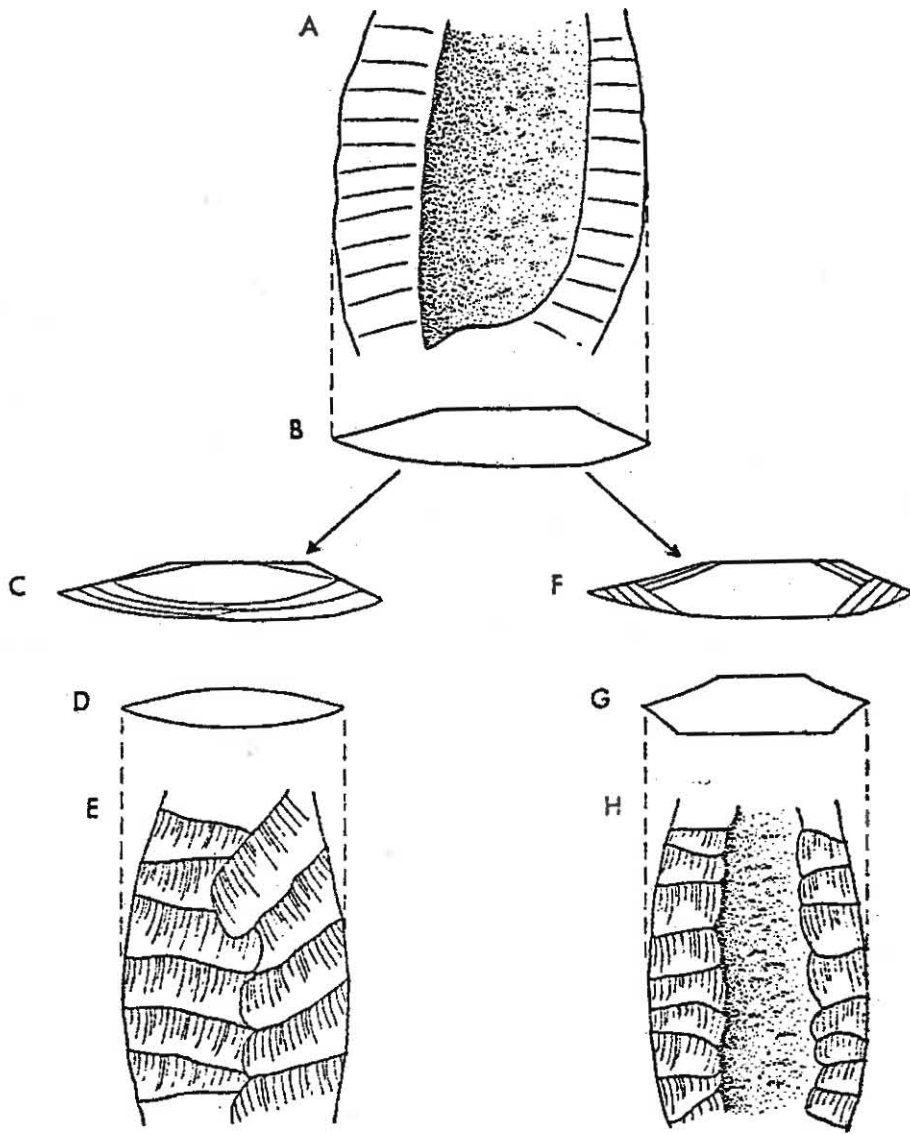


Figure 8

Thinning a biface. (A) Dorsal view and (B) cross-section of original flake. A typical product of knapping heat-altered chert: (C) cross-section showing long thinning flakes, resulting in biface with thin cross-section (D) and face view (E). A typical product of knapping unaltered chert: (F) cross-section showing short thinning flakes, resulting in biface with thick cross-section (G) and face view (H) which retains part of original flake surface. (after Rick 1978:46)

we can predict that thin bifaces used as knives will be of heated chert.

Next, heat treatment may be expected on projectile points used primarily for a piercing function. For this function, salient attributes are sharp edges and a sharply pointed tip for the task of piercing the hides and penetrating to the vitals of the animals hunted. The use of heat treated raw material for points will result in enabling a sharper edge to be flaked, as with knives. Reduced edge angles and controlled flaking will produce a sharper point tip. In addition, heat treatment will favor production of a thin smooth bifacial form which is more efficient in flight. A thin smooth point does not have irregularities on the surface to present resistance to air flow; with the greater control of flaking allowed by heat treating stone, a smooth surface finish by fine pressure flaking creates a more streamlined form. Replication experiments comparing flaking of heat treated bifaces with unheated controls have shown that starting with identical preforms, the heated material produces longer, wider, and thinner bifaces, hence larger points with less weight (Rick 1978:51; Flenniken & Garrison 1975:129). This allows the prediction that projectile points will show a high frequency of heat treatment in an assemblage where heating is practiced.

Next, consider a function of incising. While a razor-sharp edge is advantageous for cutting into soft materials, when incising or grooving hard materials such as wood, bone, or antler, heavy pressure is exerted on the tool. Here, both the properties of edge sharpness and edge durability must be taken into account. The sharp edge produced on heated material is thinner and thus more friable and less durable than an edge knapped on a tougher raw material. Initial performance as an inciser may be enhanced by the sharp edge, but through time the edge will tend to dull and crumble at a faster rate than a non-heated edge. Hence, tool use-life must be considered along with initial tool perfor-



mance. Because a strong edge is needed for an incising or grooving function, we would not predict a high incidence of heat treatment among tools of this function. The exception may be when incisers are used as light-duty tools for the ritual scarifying or tattooing of persons; this function, however, is closer to that of a cutting knife than to a chisel tool used for incising hard substances.

Another tool prevalent at prehistoric sites is the scraper. These tools are common because of their multiple uses: scraping hides in leather preparation; scraping meat from bones; scraping bark and plant material; and scraping wood in the manufacture of wooden tools and handles. The emphasis with tools of a scraping function is on the durability of edge and the strength of the tools. In contrast to tools with a cutting function, scrapers usually have steep edge retouch. Scrapers must be able to withstand the pressure of long strokes across a variety of materials. In this case, heat treatment would be a detriment to tool performance, as heated material is more brittle and would require more frequent resharpening. Thus here we would predict a low frequency of heat treatment.

Likewise, in large heavy bifaces and scraper planes, and with adzes, heat treatment is not expected. In woodworking tools the tasks necessitate a heavy durable tool, able to withstand the stress and duration of task performance. While initial cutting of wood proceeds more rapidly with a heat treated tool, edge degeneration proceeds rapidly also. Completing the task requires more frequent reworking of the edge and this interferes with performance. Mashing, pulverizing and chopping tools would also perform better if made from a durable non-heated raw material. Heavy pounding stresses tend to break apart heat treated material sooner due to the increase in brittleness.

Thus it seems that prediction of the pattern of heat treatment across

various functional categories is possible based on a knowledge of the changes in physical properties which occur when a lithic material is heated prior to manufacture of the tools. Sharper edges benefit cutting and piercing functions, while the decrease in edge durability and strength deters the functional performance of heavy-duty scraping and woodworking tools. Several questions are raised by this discussion. For instance, it is often the case that tools serve more than one function. Are multi-purpose tools benefited or hindered by manufacture from heat treated raw material? Cutting and piercing functions both benefit from a sharp edge and thin tool form, but what of tools that are used for cutting and scraping activities? It would be interesting to test empirically the frequency of heat treatment in an assemblage composed of multi-purpose tool types as opposed to one containing a wide spectrum of specialized tool types.

Finally, tool types are the product of reduction sequence trajectories as well as being direct functional endpoints. If the raw material employed is preferentially heat treated at a certain stage in the reduction sequence, it follows that all tools made from this point on will exhibit heat altered properties. If cores are heated, the resulting flakes and flake tools will be heat treated. If flakes are detached and some heated, the tools made from these will be heat altered while other tools remain natural. There is a wider range in this resulting assemblage because treated flakes can be finished into thin biface forms, while untreated flakes unifacially retouched for use as scrapers. The reduction sequence incorporates in addition the reuse and recycling of tool forms. If tools of one function are preferentially made from heat altered chert and later reworked into another functional form, the resultant tool will still be heat altered. Some tools may therefore exhibit heat treatment as a result of the place of the original tool or blank in the

reduction sequence rather than because their intended function dictated the use of heat treated material.

Heat treatment must be viewed within the context of the total lithic technological process, not as an isolated technique. Heat treatment affects resource procurement, tool manufacture, and tool function and re-use. Predictions can be made for the presence of heat treatment in certain circumstances, but these must be tested in specific cases in order to confirm and elaborate the model. To date there have been too few lithic analyses which include raw data on the presence of heat treatment among different categories of source material, manufacture method, and function. However, with the limited data at my disposal, I would like to test the association of heat treatment in various situations to see where my predictions explain the patterns and where there are exceptions to the model.

In this section I will be using data from six sites in North America, as displayed in Table 1 below. The sample was not chosen for completeness, but represents the site reports I could obtain which have raw data on heat treatment. The data set exhibits several problems plaguing the systematic study of heat treatment in lithic assemblages. To begin with, there are few analyses which discuss heat treatment in more than a cursory fashion. Few present information on both the presence and absence of heating among the artifact types. Second, comparisons of heat treatment across tool types in different assemblages is thwarted by the lack of consistency in tool type definitions. This can be seen by the frequent blanks in Table 1. This lack of standardization hinders not only heat treatment studies but also lithic analysis in general.

Finally, and most critically, there is the problem of obscuring possible temporal variability by the presentation of heat treatment frequencies for the site as a whole. Unless the assemblage analyzed for the presence of heat treat-

Table 1

Heat Treatment by Tool Type  
(percent frequency)

| tool type                           | Wells Creek site, Tennessee<br>Paleo-Indian period<br>Dragoo 1973 | Brand site, Arkansas<br>Early Archaic period<br>Anderson 1979 | Graham Cave, Missouri<br>Archaic period<br>Klippel 1971 | Collins site, Missouri<br>Early Woodland period<br>Klippel 1972 | Von Elm site, Oklahoma<br>Archaic-Plains Woodland period<br>Hartley 1974 | Knapp Mounds, Arkansas<br>Woodland-Early Mississippian<br>Anderson 1979 |
|-------------------------------------|---|---|---|---|--|---|
| projectile points                   | 50%   | 24%   | 70%   | 80%   | 55%  | 48%   |
| tools on points                     |   |   |   |   |  |   |
| scrapers                            | --  | 43  | 91  | --  | --   | --  |
| drills                              | --  | 100   | 57  | 54  | 100  | --  |
| other                               | --  | 40  | --  | --  | --   | --  |
| knives/thin bifaces                 | 33  | --  | 83  | 73  | 50   | --  |
| preforms                            | 90  | 33  | --  | --  | --   | 85  |
| thick bifaces/choppers              | 39  | --  | 20  | 43  | 40   | 13  |
| scrapers                            | 0   | 23  | --  | --  | 52   | --  |
| gravers                             | many  | 27  | --  | --  | --   | --  |
| pieces esquillees                   | --  | 31  | --  | --  | --   | --  |
| blades                              | 0   | 23  | --  | --  | --   | --  |
| adzes                               | --  | 21  | --  | --  | --   | 9   |
| cores                               | 0   | --  | 0   | 3   | --   | 3   |
| retouched/<br>utilized flakes       | --  | --  | 24  | 21  | 50   | --  |
| total heat treated<br>in assemblage | 17%   | 26%   | 57%   | 47%   | 46%  | 41%   |
| sample size                         | 12,952  | 637   | 1555  | 1287  | 21,105   | 600   |

ment is from a single cultural level, it is difficult to discriminate the influence of factors of intentional heat treatment from the influence of changing heating practices through time. Although most of the site assemblages presented in Table 1 are interpreted as single component sites, it is rare that lithic heat treatment analysis is separated into frequency of heat treatment by tool type for each cultural level in the site. Strict control of this temporal variable extends the reliability of interpretations on these data. Given these problems inherent in the present reporting of data on heat treatment in lithic assemblages, the percentage frequencies given in Table 1 should be viewed as indicating trends rather than being statistically significant proofs of the dominance of one factor in the heat treatment distribution.

The primary data set which I use to test the predictions represents a wide temporal and geographic range. Heat treatment appears in all chronological periods in North America from the Paleo-Indian to the Mississippian. The Wells Creek site is a Paleo-Indian habitation and workshop site in Tennessee, located near an abundant supply of chert used by many prehistoric occupants of the area (Dragoo 1973). Although the lithic analysis is not segregated by occupational level, all the material is associated with the Paleo-Indian period. The Archaic period (10,000 to 3,000 years B.P.) is here represented by two sites, the Brand site and the Graham Cave site. Brand is a multicomponent site in Arkansas; only the Early Archaic "Dalton" assemblage is analyzed here (Anderson 1979:236). The Graham Cave site in northern Missouri has occupation spanning several temporal periods, but the analysis is limited to the Archaic period. A problem presents itself here, owing to the temporal variation in the practice of heat treatment within this period. The lowest level of Archaic occupation (ca. 9-10,000 years B.P.) shows a general lack of heat treatment among the lithic artifacts, while the upper layers (ca. 7-9,000 years B.P.) show a high frequency

of heat treatment; unfortunately the lithic analysis presents the Archaic assemblage as a temporally homogeneous unit (Klippel 1971:22, 43-44). The Collins site, also in Missouri, has an Early Woodland assemblage which has been interpreted as the conjunction of two distinct chipped stone manufacturing traditions, one heated and the other untreated, in a single component occupation (Klippel 1972:47). The Von Elm site in the Kaw Reservoir of Oklahoma was excavated in four areas corresponding to the clustered surface debris; with deposits spanning the Middle Archaic to Plains Woodland period, these four areas "may represent somewhat different components" (Hartley 1974:124). Although heat treatment frequencies are presented as total heat treated flakes per area, the differentiation of artifacts by tool type is for the assemblage as an entirety. The individual areas show from 48 to 57% heat treatment of flakes, which is not a wide range of variance. Although the archaeologist doubts that the practice of heat treatment can be used as a temporal indicator in the Kaw Reservoir region (Hartley 1974:123), this may be due to the disguising of temporal variability by analyzing heat treatment for the assemblage as a whole rather than by controlling for occupational area. Finally, the Knapp Mound Group, in central Arkansas, represents the latest period, with deposits from the Woodland-Early Mississippian. The site is located on an alluvial plain devoid of stone, and the sources of the raw materials used have not been pinpointed (Anderson 1979:234-5). Because of the limitations inherent in the data from several of these sites, I will also use information from other site reports to illustrate particular points; these sites will be described as they are discussed in the text.

In viewing the data presented in Table 1, certain patterns emerge. First, at the Von Elm site (Hartley 1974), there is a consistent appearance of heat treated artifacts regardless of tool type. Scrapers show a low of 40% heated

artifacts, and projectile points exhibit a high of 55% heated specimens. There is 100% heat treatment in the category of drills, however only three specimens are included in this type. Forty-six percent of the assemblage as a whole is heat treated, rather high for explanation by the random use of accidentally heated raw material. One chert type predominates in the assemblage, a fine-grained dull gray chert which outcrops locally. Although the site report does not indicate whether this chert is unusually tough or difficult to flake, this trend of overall consistent use of heat treated raw material for all types of tools suggests that heat treatment was done to improve the quality of the raw material rather than for functional reasons. This is postulated but not proven, however, owing to the possibility that the lumping of the four separate areas into the artifact analysis is masking temporal variability and homogenizing the assemblage.

Perhaps a more reliable interpretation of heat treatment to improve the quality of a raw material is demonstrated by an analysis of Tongue River Silica by D.C. Anderson (1978). Tongue River Silica is a silicified sandstone which occurs as cobbles in glacial gravels in western Iowa. This raw material is almost impossible to work in its native state, yet is readily available in an area where there is a paucity of workable stone due to the absence of bedrock sources of chert. Anderson found this raw material type comprising at least 40% of the total lithic assemblage at 26 of the 179 sites examined in this analysis; in these 26 site assemblages, the percentage of artifacts demonstrating evidence of heat treatment is greater than 80% of the Tongue River Silica assemblage on all but two sites (Anderson 1978:154-155, Table 3). It appears that where Tongue River Silica is extensively used as a raw material in a lithic assemblage, it is used primarily in a heat treated state. Because the stone is available in areas where high quality stone is scarce, and shows greatest use in

the Archaic and Woodland periods when populations were low and there was little trade as a means of obtaining high quality "exotic" stone, this case is interpreted as an example of the use of heat treatment to improve the quality of an otherwise marginally suitable lithic material.

Patterns in the data in Table 1 can also be related to function of specific tool types. Compared to the frequency of heat treated artifacts in the entire assemblages, certain tool categories present higher or lower percentages. Consistently, projectile points, knives, and thin bifaces show a much higher frequency of heat treated specimens than do the categories of scrapers, choppers, and heavy bifaces. This pattern conforms to the predictions. The Graham Cave and Collins sites in Missouri (Klippel 1971, 1972) both show high frequencies of heat treatment among points and thin bifaces (used as knives or preforms), and low frequencies in the categories of thin bifacial choppers, cores, and retouched and utilized flakes. This pattern is also seen at the Knapp Mounds. Here arrowpoints and arrow preforms show a high percent of heat treatment, while heavy choppers, adzes, and cores have a low incidence of heating. Thus it seems that when comparing heat treatment within assemblages, heat treatment is correlated with the intended function of the tools, as predicted.

Heat treatment of bifaces and projectile points is often mentioned in the literature. This may reflect intentional heat treatment of tools designed for a cutting and piercing function, and selection of untreated raw material in the manufacture of tools intended for heavy-duty chopping and scraping activities. Dragoo (1973:20) notes that in the Wells Creek Paleo-Indian material, about half of the bifacial cores were heat treated, and these were more carefully and finely chipped than the unheated bifacial cores. He postulates that cores destined for reduction to small refined tools were heated at the biface core stage.



The Wells Creek sample exhibits some heat treatment among all the bifacial tool categories, whereas none is found on the unifacially chipped tools. The question arises: how much of the variation observed in heat treatment of certain tool types can be attributed to manufacture method rather than specifically to the intended function of these tool types? Points and thin bifaces tend to be more often knapped by soft hammer percussion and pressure retouch than are heavy-duty tools. Because heat treatment increases the ease and control of knapping by these manufacture methods, bifacial tools may have been heat treated for increased workability or for the sharper cutting edge.

Kraft (1973) gives a heat treatment analysis for debitage at the Plenge site, a Paleo-Indian period occupation in New Jersey. The predominant raw material represented is jasper; of the diagnostic artifacts, 65% are of brown (unaltered) jasper and 24% are of red (heat treated) jasper. In the analysis, 3279 jasper flakes, cores, and chips are categorized by type and raw material (see Table 2). Of this sample, 27% are brown jasper and 73% are heat treated jasper. From this one might postulate that the debitage at the site is predominantly the result of reworking the heat treated tools. Among the categories with higher than average percentages of heat altered jasper are: small retouching flakes, prepared striking platform flakes, decortication flakes, and chips with no striking platform nor cortex. On the other hand, bifacially trimmed edge flakes, blocky fracture flakes, and exhausted cores show a higher relative frequency in the unheated category. From this we can infer that heat treatment was not performed on cores or at the time of the initial reduction of large blocks. Small cobbles may have been treated, as decortication flakes are more frequently heated. The unheated bifacially worked edge flakes present an anomaly. However, small retouch flakes show a high frequency of heat treatment, suggesting that bifacial finishing and reworking was performed on heated material.

Table 2

Debitage Analysis from the Plenge site, N.J.  
 Heat Treatment by Debitage Type  
 (Kraft 1973:111)

| <u>debitage type</u>                         | <u>% heated</u>  | <u>% unaltered</u> |
|--|------------------|--------------------|
| small retouching flakes                      | 87 %             | 13 %               |
| prepared striking platform on decort. flakes | 87               | 13                 |
| prepared striking platform w/ ground margin  | 81               | 19                 |
| prepared striking platform w/out grinding    | 80               | 20                 |
| simple flakes, no platform, no cortex        | 80               | 20                 |
| decortication flakes, no platform            | 76               | 24                 |
| blocky fracture flakes, no cortex            | 63               | 37                 |
| bifacially trimmed edge w/ grinding          | 52               | 48                 |
| blocky fracture flakes with cortex           | 49               | 37                 |
| bifacially trimmed edge w/out grinding       | 47               | 53                 |
| exhausted core, no cortex                    | 10               | 90                 |
| exhausted core with cortex                   | 6                | 94                 |
| total specimens = 3279 jasper flakes         | $\bar{X} = 73\%$ | $\bar{X} = 27\%$   |

Finally, variation in the heat treatment of an assemblage may lie in the reduction sequence and recycling of tools. Heating at the biface preform stage seems to be supported by data in Table 1 above. If biface preforms are heat treated, tools made from these will exhibit signs of heating, as will the debitage from finishing and retouching bifaces. The high frequencies of heat treatment among the categories of thin bifaces, points, and tools made on reworked points supports this prediction. From the biface preform stage, the form is chipped down to a finished knife blade or point. Reworking of worn edges and resharpening reduces the width, but a wide blade permits long tool life. After primary use, the dulled and worn tool can be retouched into a drill or scraper. The strong medial ridge can be utilized in drilling, and bifaces broken in half by lateral snap can be retouched steeply and used as endscrapers.

Table 1 gives consistently high frequencies for heat treated tools made on reworked points; this seems to be the result of the place of these tools in the reduction/recycling of heated bifaces rather than the functional utility of heat treatment for these types. Anderson (1979:246-247) reports the frequency of heat treated artifacts as 23% for scrapers and 43% for scrapers made on points at the Brand site in Arkansas. At the same site there is a high frequency of heating in the adze category. It was predicted that adzes, because of their heavy woodworking function, would show minimal evidence for heat treatment. The presence of heating is attributed to the recycling of adze fragments, heated and reworked into knives, wedges, and cores (Anderson 1979:329). Here, heating is most often found in the reworked adze-knife category. These data indicate the use of heat treatment in an industry conservative in its use of raw material; chert is readily in river gravels but these vary in quality and are exposed about 16 km from the site (Anderson 1979:237).

Projectile points as predicted show a high frequency of heat treatment.

Frison (1978:337-338) emphasizes the importance of point design for the hunter, the necessary attributes being a "sharp point to penetrate the hide, sharp distal blade edges to open a hole for the remainder of the point and shaft, and a hafting element designed to absorb the thrust without splitting the shaft." Heat treatment allows for the sharp edges, and facilitates as well the controlled and careful flaking usually seen on points.

Looking at the data in Table 3 for heat treatment frequencies of various point types in several assemblages, the internal variation in this general category becomes apparent. I would like to examine this variation more closely as a microcosm of variation in entire lithic assemblages. Several factors may be responsible for this variability in heat treatment: differences in raw material, variation due to temporal discontinuity, functional variability or degree of functional specificity, and stylistic or non-functional formal variation.

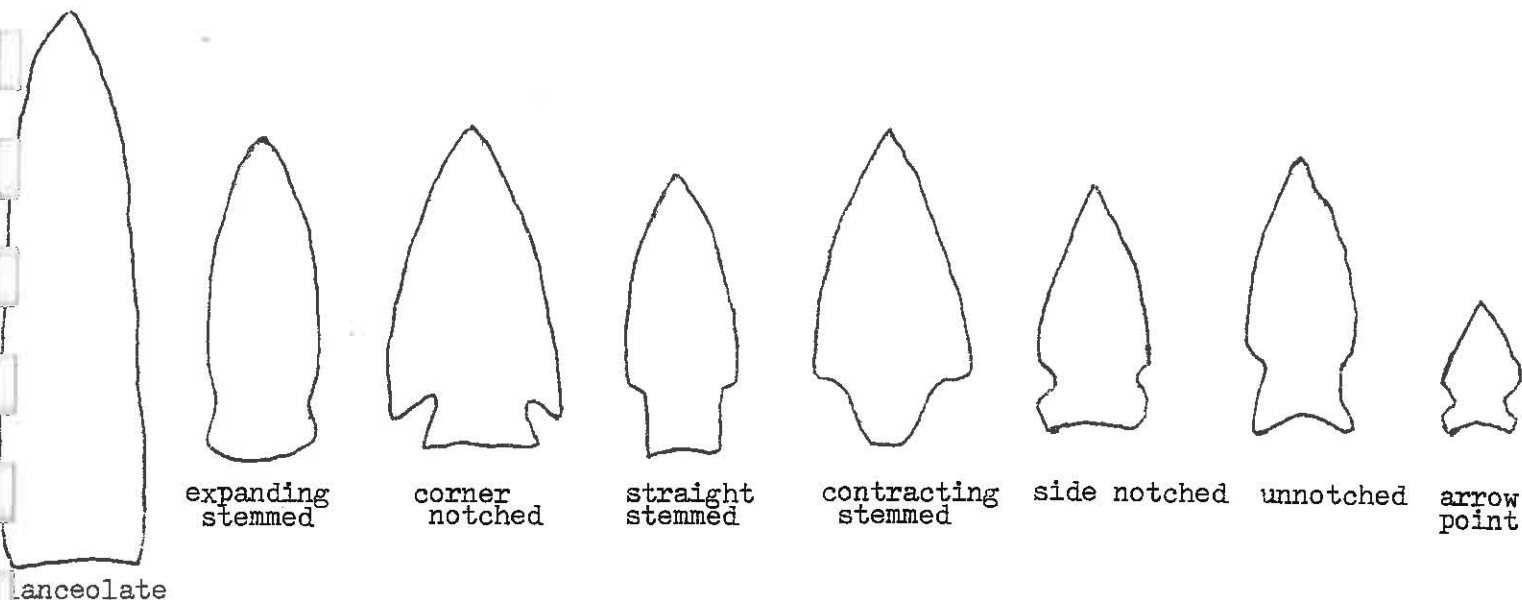
Raw material may affect the variation in heat treatment of projectile point types. Not only are some cherts tougher than others and of lower quality, hence needing heat treatment, but also some raw materials are more amenable to heat treatment because they tolerate temperature fluctuations with less heat damage. In Ahler's analysis of projectile points from Rodgers Shelter, Missouri, heat treatment does vary by raw material type, ranging from 83% heating of "spotted" chert to 48% heating of the "solid" type of chert (Ahler 1971:Table B). At Graham Cave and the Collins site, the dominant chert source is from the limestones of the Burlington Formation, which outcrops in the vicinity of both sites (Klippel 1971:9-11; 1972:2). Since here the variable of raw material type is controlled, the variation in heat treating of points at these sites must arise from a different cause.

Temporal variation may influence the presence of heat treatment within a

Table 3

Heat Treatment by Projectile Point Type

|                                     | Graham Cave<br>Klippel<br>1971 | Collins<br>Klippel<br>1972 | Rodgers Sh.<br>Ahler<br>1971 |
|-------------------------------------|--------------------------------|----------------------------|------------------------------|
| <u>point type</u>                   |                                |                            |                              |
| lanceolate                          | 26%                            | --                         | 59%                          |
| expanding stem                      | 78                             | 80                         | --                           |
| corner notched                      |                                |                            | 66                           |
| straight stemmed                    | 14                             | 40                         | 88                           |
| contracting stemmed                 | 75                             | --                         | 48                           |
| side notched                        | 78                             | 91                         | 64                           |
| unnotched                           | --                             | --                         | 100                          |
| arrowpoints                         | 75                             | --                         | --                           |
| point fragments                     | 73                             | 81                         | --                           |
| total heated in<br>point assemblage | 70%<br>n=374                   | 80%<br>n=273               | 64%<br>n=114                 |



Generalized Outlines of Projectile Point Types  
(after Ahler 1971:9)

lithic assemblage. This has been eliminated as a factor from the Rodgers Shelter analysis, as all the points come from a single level of the site. At Graham Cave, however, the point categories of expanding stemmed/corner-notched points and side-notched points show the highest frequency of heat treatment (78%), and predominate in the upper two levels of the site; lanceolate points, which occur in the lower levels, show a low (26%) incidence of heat treatment (Klippel 1971:44). Similarly, in the analysis of the Koster site in Illinois, Cook (1976:127-150) distinguishes heat treatment of point types as a factor of time. While none of the points show heat treatment in the Titterington phase assemblage, in the succeeding Helton phase there is between 26% and 77% heat treatment of the point types. Several analyses have traced temporal trends in heat treatment and found a high frequency in the Archaic and decreasing importance of the practice through the Woodland and later periods (Johnson, Yapple & Bradley 1972; Christenson 1977). The temporal variable is best examined in specific situations, rather than assuming that this trend applies everywhere in North America. Klippel (1970) finds an opposite pattern in northern Missouri: Late Archaic sites lack heat treatment of lithics, while Woodland sites exhibit evidence of heating on artifacts. The Early Woodland Collins site is interpreted as a meshing of the heated and nonheated lithic traditions by "peoples responsible for the 'new' complex. . . articulating with peoples already established in the area" (Klippel 1972:55).

The recent rash of lithic use-wear analyses, if not internally consistent in interpretation, have made headway in expelling the myth of discrete functions for discrete morphological categories of lithic tools. Projectile points can no longer be assumed to have a single consistent function. In his analysis of 114 "projectile points" from a single occupational stratum from Rodgers Shelter, Ahler (1971:119) found functional diversity among this single morpho-

logical category. Less than one-quarter of the specimens exhibited use-wear indicative of primary use as a projectile; other functions determined were heavy and light-duty cutting and sawing, piercing, whittling, and scraping. Use-wear associated with activities involving both hard materials (wood, bone, antler) and soft substances (meat, plants) was found. In Table 4 the percent frequencies of heat treated specimens are correlated with the functional categories determined by edge wear. The variation in heat treatment by function is apparent.

Forms functioning primarily as projectile points have a relatively high frequency of heat treatment (76%). On the other hand, patterns emerge which were not expected. All the points functioning as heavy-duty sawing or slicing implements are heat treated, as are the scraping and grooving tools. The tools used for cutting and slicing of soft materials have a lower frequency of heat treatment than was expected. These observations run counter to those predicted from the decrease in edge durability of heat treated material, which would favor heat treatment in tools used for cutting soft materials rather than hard. This indicates to me that there are probably other factors influencing the frequency of heat treatment here besides function.

Ahler notes that the functional categories are sometimes but not always correlated with the formal types (1971:119-120). Of the twenty-three formal categories (those in Table 3 have been grouped), only one, the unnotched point type, is consistently associated with a true projectile point function. There is a strong correlation with heat treatment here, as all eight specimens in this category are made from heated material. Three formal categories of large broad "points" show functions of cutting and cleaving; 60% of these are heated. Lanceolate points in general have "less intense use wear and have greater wear pattern diversity than the broad-bladed specimens, suggesting a lack of func-

Table 4

Heat Treatment by Functional Point Type  
 Rodgers Shelter, Missouri, Ahler 1971

| <u>function of point</u>   | <u>number</u> | <u>% heated</u> |
|--|---------------|-----------------|
| projectile point   | 25            | 76 %            |
| heavy duty cleaving and cutting of<br>penetrable material (wood, plant, animal)      | 22            | 55              |
| light duty cutting, slicing, and sawing<br>(animal and plant)                        | 18            | 50              |
| piercing, separating, splitting<br>(wood, cane, bark, mussel shells)                 | 13            | 46              |
| heavy duty sawing and slicing<br>(wood, bone, antler)                                | 9             | 100             |
| specialized sawing or slicing of<br>soft material (hide, flesh, fish scales, plants) | 8             | 38              |
| whittling (wood, plant)  | 5             | 60              |
| scraping (wood, hide)  | 2             | 100             |
| burin slotting, grooving<br>(wood, bone, antler)                                     | 1             | 100             |
| uncertain  | 11            | 82              |
| totals   | n=114         | $\bar{X}=64\%$  |



tional specialization for lanceolates within the general realm of multi-purpose, light-duty cutting implements" (1971:119). Perhaps this lack of functional specialization accounts for the overall low degree of heat treatment (59%) among lanceolates. On a purely morphological level I would expect a high degree of heating for lanceolate points due to their thin narrow form. Finally, one formal category has serration of lateral edges which is highly correlated with specialized sawing or slicing activities of soft material. This type shows 30% of the seven specimens made from heated material.

Thus sometimes the formal categories correlate with certain functional categories as divined through edge-wear analysis. This is expected because some of the morphological characteristics of the point form, such as hafting element and blade thickness, are predominantly functional. The observed variation in frequency of heat treatment among various types does not always conform to the expected, however, because the formal types are composed from both functional and stylistic attributes; the difficulty in segregating these makes it hard to isolate the primary reason for variation in heat treatment. Undoubtedly the two are mixed, however, as heat treatment affects both ease of manufacture, hence potential range of stylistic forms, and functional performance.

Surface treatment, although it may be of functional importance, affects variation in heat treatment because it reflects the manufacture method. One might expect more controlled flaking to be correlated with an increase in heat treatment. Heat treatment prior to final pressure retouch, diagnosed from luster patterns of contiguous flake scars, is indicated from several site assemblages (Ranere 1971; Klippel 1972; Irwin-Williams 1966). In several cases, heat treating seems to be associated with oblique or parallel pressure flaking or "ripple flaking," which is even and regularly patterned pressure retouch across the surfaces of a point or biface. In the Rodgers Shelter analysis, all

three lanceolates with parallel-oblique pressure retouch were heat treated (Ahler 1971:136). Three out of four points from a surface collection at a site in Belize exhibit heat treatment on oblique pressure flaked forms (Hester, Shafer & Kelly 1980:9-10). In South Texas, Hester and Collins (1974:221) document a case where heat treated material was apparently preferred for the manufacture of a specific projectile point, the Shumla type, a form with serrated edges and pressure flaking commonly in a parallel-oblique pattern.

Among modern replicative flintknappers, the pièce de résistance as far as skill in flintknapping seems to be manufacture of a fluted point. In discussing the qualities necessary in a stone for the manufacture of the Lindenmeier Folsom, a fluted Paleo-Indian form, Crabtree (1966:17) cites the advantages of using heat treated material:

Heat treatment gives to the silica minerals the vitreous quality necessary for fine pressure flaking and channel flake removal. Further, treated material loses much of its tenacity, cohesiveness and toughness, but still retains its hardness. Alteration also enhances the elasticity of the stone and, therefore, allows the flake to bend and increases the worker's control for pressure retouch and in guiding the fluting flake. Heat treatment also reduces the change of a hinge fracture.

The control of fracture is an important quality for channel fluting of points, as is the decrease in hinge fracturing; this latter during the removal of the fluting flake is a common cause of failure, as a hinge fracture can easily cause the blade to snap in half (see Figure 9). Crabtree reports that there is evidence at the Lindenmeier site of heat treatment, but does not go into detail; the site report does not mention heat treatment at all (Wilmsen & Roberts 1978). Other evidence for the heat treatment of fluted points comes from the Panamint Valley, California. Here there are examples from the Fluted Point Co-tradition of the Paleo-Indian stage, of large pressure flaked points with basal thinning

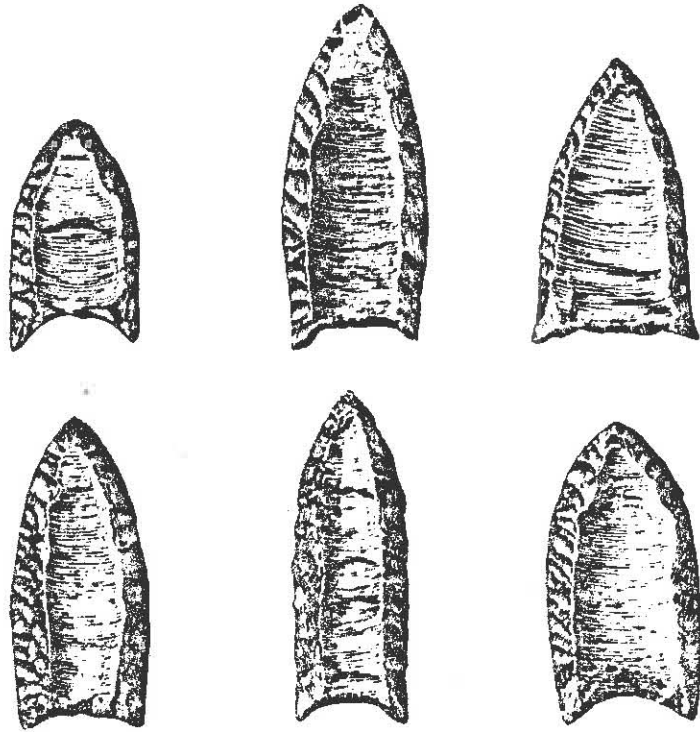


Figure 9a. Representative sample of Lindenmeier Folsom fluted points.  
(after Wilmsen and Roberts 1978:115)



Figure 9b. Point broken during manufacture by a hinge fracture, and then retouched into a scraper.  
(after Wilmsen and Roberts 1978:Fig.148)

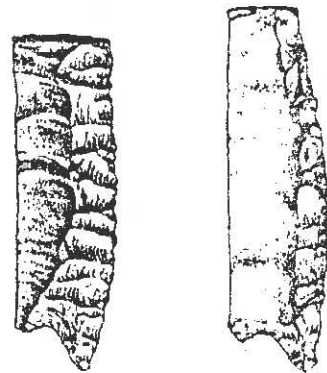


Figure 9c. Points broken by splitting during manufacture. (after Wilmsen and Roberts 1978:Fig.149)

or fluting, made of heat treated chalcedony (Davis 1968; Davis & Shutler 1969; Davis 1973). These Fluted Point hunters used fine-quality stone and practiced heat treating and pressure flaking, in contrast to the later "Western Lithic Co-tradition" in this region, where the lithic inventories consist of coarse, heavy percussion flaked tools made from basalt (Davis 1968:44-46). Thus there are technical incentives for the heat treating of certain projectile point forms.

From this discussion of heat treatment of projectile points it is apparent that there are several potential sources of the variability in presence and degree of heat treatment within a lithic assemblage. Both within and between tool types, the main sources of heat treatment variation result from differences in the raw material, manufacture methods and place in the reduction sequence, and tool function, as well as changes in heating practices through time. Within each of these stages in the lithic technological process, differences in heat treatment frequencies occur because the changes in physical properties of the stone incurred by heating present some advantages and some hindrances to raw material and tool performance. The decision to heat a particular raw material prior to manufacture into a stone tool is situation-specific. From a model which predicts the range of potential reasons for heat treatment, the lithic assemblage in question must be examined as the product of a specific lithic technological system to see which of the potential reasons for heat treatment is most important. From the patterns of heat treatment within the specific lithic assemblage, the lithic analyst will be able to postulate which reason for heating seems to be most strongly operative in the given cultural context.

## Conclusion

Heat treatment may enter into any stage of the lithic technology, affecting the character of the final product, the tool deposited on an archaeological site. By means of a model we can predict potential reasons for heat treatment. However, because this practice is a technical choice available to the flint-knapper, the decision to heat treat will be the result of a set of circumstances acting in a specific situation. Although the model isolates the factors, in real situations there is a multiplicity of factors working concurrently. We have predicted that lithic material will be heated when the local raw materials are of poor quality for knapping, or when good quality stone is at a distance from the site. Heat treated material may be selected for the manufacture of thin bifaces, especially by controlled soft percussion and pressure flaking techniques. Heat treatment might be chosen when a thin sharp edge is needed on the finished tool. The gross quantity of heated lithic artifacts in an assemblage may increase if heat treatment is regularly performed in the beginning of the reduction sequence, although it appears that preforms and large flakes are selectively heat treated prior to reduction into bifacial tools. In the case where heat treatment is practiced at the quarry site after primary reduction into preforms, transportation of heated raw material to the habitation site leads to a preponderance of heated artifacts and manufacturing debitage at the home base. These predictions should be considered in explanations of the patterns of heat treatment distribution in a lithic assemblage.

Having investigated this phenomenon in detail over the preceding pages,

there still remains the question of its significance. Heat treatment is only one aspect of a lithic technology, and as such was not even discussed in the literature until recent decades. Documentation of the extent of this process geographically and temporally must come from the integration of heat treatment studies as a standard practice in lithic analyses. Although the master flint-knapper Errett Callahan (1979:169) maintains that heat treatment is no substitute for knapping ability, I would argue that heat treatment reflects a control over and efficient use of lithic raw materials indicative of a sophisticated technology. At this stage some speculations on the significance of heat treatment are warranted.

First, on a technological level, the recognition of the presence of heat treatment in the manufacture of stone tools leads to a realization of the broad spectrum of techniques potentially available to the prehistoric craftsman. The use of a heat treated raw material for the manufacture of stone tools demands special techniques; in the same way that the identical battery of manufacturing methods is not employed for working obsidian as for working rhyolite, working heated chert will demand different consideration than the knapping of the same chert in its unheated state. Similarly, for maximum functional efficiency, the uses of a heat treated tool will be different from the functions of an untreated tool. The increase in specialization of function demonstrated by the use of heated material for the manufacture of certain tool types demonstrates an increased sophistication in the stone tool technology.

In the sense that heat treatment is a technique utilizing only those materials found in nature, it is a primitive or fundamental technique. This is not to imply that the process is simple or unsophisticated. Heat treatment demands a control of the heating medium, and the weighing of the costs and advantages of the use of heated material for the specific tool function and

form intended.

Secondly, heat treatment must be considered as a technique for maximizing exploitation of raw materials from the local environment. As a technological phenomenon, heat treatment involves the procurement of raw material from the environment, and the use of local source materials in preference to traveling afar to obtain exotic high quality material. Heat treatment can redefine and extend the range of exploitable resources in the local environment. If a technological advance entails increased energy extraction from the environment, then heat treatment is an advancement allowing a group to use local stone in a more efficient manner by including previously "marginal" material in the category of "workable stone." By broadening the definition of workable stone resources, more intensive exploitation of the local environment results.

Finally, heat treatment of siliceous materials has significance in the context of "pyrotechnology" or the technology of fire use and control. Heat treatment reflects a sophisticated control of fire which in many areas predates the development of a ceramic or metal technology (Epstein 1979:36; Purdy 1978: 35). It is interesting in this light to examine other cultural uses of fire; the use of fire to alter properties of other substances may have led to experimentation in heating siliceous stone. Alteration of inorganic materials appears in several areas documented ethnographically. The Pomo Indians of California "roasted" or "baked" nodules of magnesite prior to manufacture into beads; the heating changed the dull white magnesite into a lustrous red, pink, or yellow color, adding to the value of the beads when traded (Pitzer 1977:8). Steatite or soapstone was used frequently in North America for smoking pipes because it is characteristically soft for carving, and will not break when heated. The Yokut tribe of the lower San Joaquin River, California, manufactured steatite bowls which were then "cooked. . . overnight in a fire. This cooking process

had the effect of hardening or tempering the pot so that its durability was increased" (Heizer & Treganza 1960:291). Several tribes in California altered hematite or manganese by burning the minerals prior to pulverization for red or black face paint (Ibid.:294). There is sporadic evidence for the aboriginal working of native copper by cold-hammering followed by annealing in a fire to render the worked copper less brittle (Mowat 1958:87; Forbes 1950:317; West 1929:59).

Heat was also frequently used to alter various organic substances. Examples of this range from charring wood to facilitate scraping and manufacturing of wooden implements (Osgood 1940:196), to steaming wood for straightening arrowshafts (Schumacher 1960:306), to heating resins and glues in the hafting of tools (Gould et al 1971:161). In addition there is the practice of heating plant and meat material in cooking, in which various structures might be used such as roasting pits, stone-lined pit ovens, stone-boiling troughs, or stone slabs placed over an open fire. Fire is a subsistence tool, a means of personal comfort, and often a ceremonial element (Gould 1971).

These many and varied uses of fire emphasize the point that the heat treatment of siliceous stone is not a technique in a vacuum. The understanding of heat treatment demands investigation of the practice within the context of the culture as a whole. A familiarity with the ability of fire to alter chemical or physical properties of various organic and inorganic substances may have led to the experimentation by the flintknapper of the effects of fire on lithic raw materials. Control of the medium of fire is definitely prerequisite to complex ceramic and metal technologies. The study of the function of fire in pre-industrial societies thus overlaps the study of the history of technology.



Appendix

Condensed Data from Heat Treatment  
Replication Experiments

| <u>Source</u>                  | <u>Raw Material</u>                          | <u>Heating Method</u>             | <u>Temp. Range</u>   | <u>Results</u>  |
|--------------------------------|--|-----------------------------------|--|---|
| Behm & Faulkner<br>1974        | Hixton quartzite<br>(Wisconsin)              | preforms in sand in oven          | to 750° C., held few hrs., gradual cooling                 | color change if Fe present at 245° C.; no luster change; no weight loss; no discerned improvement in flaking quality.   |
| Flenniken & Garrison<br>1975   | novaculite<br>(Arkansas)                     | preforms in sand in kiln          | 200° C., 450° C., 500° C., 48 hrs. heating & cooling.      | no color change; luster change at 450° C.; comparative flaking--less force necessary to break, no step fractures, longer, more controlled flakes, increased microfracture density (microscopy). |
| Mandeville & Flenniken<br>1974 | Nehawka chert<br>(Nebraska)                  | preforms in pit w/ coals and sand | to 325° C. in 3 hrs. cooled 20 hrs.                        | color change from gray to pink; luster change, weight loss; comparative biface knapping--thinner bifaces, greater control, longer/larger flakes, fewer hinge fractures.                         |
| Patterson<br>1979a             | stream cobble cherts<br>(Fayette Co., Texas) |                                   | heated to 260° C., held 4 hrs.                             | larger size flakes w/ heating; higher weight % in all size categories; less force req'd; cleaner fractures produced.  |
| Patterson<br>1979b             | Flint Ridge cherts<br>(Ohio)                 | flakes in home oven               | heated for 1 hr. to 260° C., held 4 hrs., gradual cooling. | surface color changes, luster change, but these variable--only 40% had both luster & color change.  |
| Perino<br>1971a                | Illinois source                              |                                   |  | color change, luster change   |

| <u>Source</u>                       | <u>Raw Material</u>                 | <u>Heating Method</u> | <u>Temp. Range</u>  | <u>Results</u>  |
|-------------------------------------|-------------------------------------|-----------------------|---|---|
| Perino<br>1971a                     | Kay Co.,<br>Oklahoma chert          |                       | 400° F. to<br>800° F.   | color change from tan<br>to red, luster change<br>to smooth texture.  |
|                                     | Wyoming flint                       |                       | 250° F.   | no color change, luster<br>change to glossy texture<br>and improved quality.  |
| Pickenpaugh<br>& Collins<br>1978    | Flint Ridge<br>cherts<br>(Ohio)     | furnace               | raised to<br>350° C., held<br>12 hrs.,<br>cooled 6 hrs.               | considerable variation<br>in results; some lacked<br>improvement in workabi-<br>lity; some no luster<br>change, most had color<br>change or cortex reddening.                             |
| Purdy &<br>Brooks '71,<br>Purdy '74 | Florida<br>cherts                   | oven                  | multiple<br>tests, both<br>gradual &<br>rapid heating                 | color change at 240°-<br>260° if Fe; luster change<br>at 350°-400° C.; weight<br>loss; no comparative<br>knapping done; decrease<br>in tensile point strength,<br>transgranular fracture. |
| Rick 1978                           | Burlington<br>cherts<br>(Ill., Mo.) | kiln, oven            | multiple<br>test<br>conditions  | color change dependent on<br>original color; distinct<br>luster change; weight loss;<br>ease of flaking on altered<br>specimens.  |
| Toll 1978                           | quartzite                           |                       | gradual heat<br>to 375° C.,<br>held 24 hrs.,<br>gradual cool-<br>ing. | color change ranges with<br>iron content; no luster<br>changes; no changes in<br>workability.   |

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