Aboriginal Thermal Alteration of a Central Pennsylvania Jasper: Analytical and Behavioral Implications

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ABORIGINAL THERMAL ALTERATION OF A CENTRAL PENNSYLVANIA JASPER: ANALYTICAL AND BEHAVIORAL IMPLICATIONS

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The aboriginal thermal processing of Bald Eagle Jasper in Central Pennsylvania is described in terms of the chemical and physical changes that occur in this material. Heat treatment is shown to transform the jasper's goethite component to hematite and to improve its workability by reducing its fracture toughness by one-half. This is accompanied by a yellow to red color change. The role of thermal alteration in the local lithic technology is inferred from laboratory heating experiments and from an analysis of lithic artifacts from the Houserville Site (36 Ce 65), a jasper workshop. The prehistoric utilization of this material is analyzed from a regional perspective. The results have implications for aboriginal social organization in Central Pennsylvania.

ARCHAEOLOGICAL EXCAVATIONS at a prehistoric jasper workshop (Figure 1) have posed a number of questions concerning the aboriginal utilization of this material for the manufacture of stone tools. Systematic surface collections and test excavations have yielded over 5,000 lithic specimens, including cores, debitage, and bifacially shaped tools. The material, known locally as Bald Eagle Jasper, occurs in the immediate vicinity of the site as nodular float material. Unaltered specimens are exclusively yellow in color, while artifactual materials may be yellow, dark red, or a bicolor combination of both yellow and red. The red areas of the bicolored tools are frequently adjacent to obvious fracture origins, as discussed by Kerkhof and Müller-Beck (1969). The possibility of a yellow-to-red color change as a consequence of tool manufacture thus becomes obvious. Since color changes in minerals are often related to elevated temperature exposures, it seemed probable that the Bald Eagle Jasper was routinely subjected to intentional thermal processing to improve its workability.

It is now widely accepted that heat treatment or thermal processing may improve the workability of certain lithic materials, and that the process was known and exploited by many prehistoric peoples. Since Bald Eagle Jasper in its native state is somewhat variable in grain size and contains other mineral inclusions, the aboriginal populations who exploited it for tool manufacture may well have employed heating techniques to improve its fracturing characteristics. This paper presents an evaluation of this hypothesis. First, the physical and chemical changes responsible for the yellow-to-red color alteration are ascertained, then the potential benefits of the heat treatment process are identified. The application of thermal processing to the Houserville assemblage is examined through an analysis of the core reduction sequence represented by this assemblage. Finally, the temporal and spatial parameters of jasper tool production in the region surrounding the site are investigated and found to have important implications with regard to period-specific lithic preferences. The results of these analyses provide insights into prehistoric population adaptation and resource exploitation in Central Pennsylvania.

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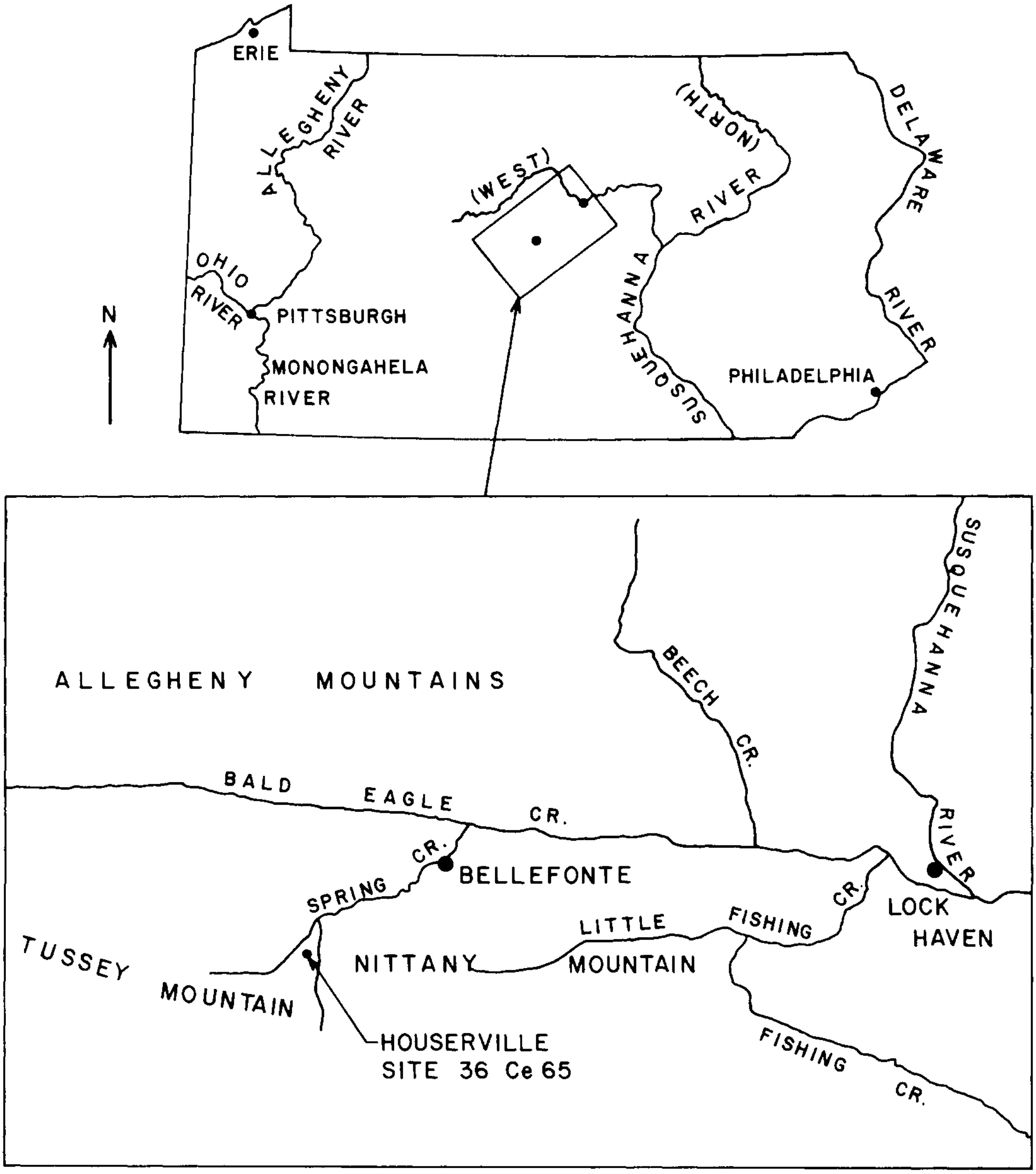

Figure 1. Location of the Houserville jasper workshop in Central Pennsylvania.

THE THERMAL ALTERATION OF JASPER

Not all siliceous materials require thermal processing. Contemporary stoneknappers have amply demonstrated that many deposits can be worked quite satisfactorily without heat treatment. Nevertheless, references to intentional thermal alteration processes having been employed prehistorically in North America are commonplace. For example, Anderson (1971), Sollberger and Hester (1973), Collins and Fenwick (1974), Flenniken and Garrison (1975), and Melcher and Zimmerman (1977) have recently presented convincing evidence of thermal alteration processes in the greater Mississippi basin. Mandeville (1973) has thoroughly reviewed the North American and worldwide references to the prehistoric heat treatment of siliceous materials during stone tool manufacture.

It is evident that there are numerous and sometimes conflicting reports regarding the identification of artifacts that have been subjected to heat treatment. However, researchers have postulated two types of aboriginal thermal processing. First is a treatment based on thermal shock, in which water dripping from a feather, reed, or stick is applied to the heated stone. Presumably, this technique caused portions of the stone to spall off, such that after repeated heatings and thermal shocks, the desired form was achieved. The second technique is the application of a controlled low-temperature heat treatment ($<500^\circ$C) which leaves the stone in a state that is readily shaped or flaked. Ellis (1940) and Purdy and Brooks (1971) effectively discredit the thermal shock-based technique, primarily because of its rather uncontrollable nature. Crabtree and Butler (1964), Purdy (1975), and Rick (1978) all support versions of the latter low-temperature technique.

Change in Color

The Bald Eagle Jasper at the Houserville site is a microcrystalline quartz with a characteristic yellow color. In bulk it varies slightly about Munsell 10YR 5/6 (Munsell 1946), but in a translucent petrographic thin section it is lighter, as expected, registering Munsell 10YR 6/10 (Munsell 1946). This particular jasper deposit exhibits variable grain size and some other mineral inclusions. Consequently, its quality is suboptimal from the stoneknapper's perspective. Relatively uniform bulk specimens of the material were chosen for laboratory analysis. From these, samples were cut with a diamond saw into approximately 1-cm cubes. These were subsequently subjected to standard laboratory tests to discover the chemical and physical changes associated with low-temperature heat treatments and the yellow-to-red color change. Finally, a number of heat-treated specimens were measured for their fracture toughness, K_C, to specifically ascertain the effects of the thermal heat treatment on the ease of fracturing.

Preliminary tests indicated that the yellow Bald Eagle Jasper readily changed to a red color when subjected to moderate temperatures. A systematic series of heat treatments was conducted to document the process of color change. The heat treatments consisted of several components, including: (1) examining the effects of a 3-hour thermal treatment in an oxidizing atmosphere (air) at increasing temperatures using a gradient furnace, (2) annealing in air (oxidizing) at 400°C for 24 hours (3) annealing for 24 hours in a dry hydrogen (reducing) atmosphere at 275°C, and (4) heating rapidly by inserting specimens into a preheated furnace containing air (oxidizing). The first test (1) consisted of heating a number of the cubic specimens in air (an oxidizing atmosphere) in a thermal gradient furnace for a period of 3 hours, then allowing them to cool in the furnace. Beginning at room temperature, the maximum temperatures reached were 100°C, 150°C, 200°C, 250°C, 316°C, 380°C, 486°C, 532°C, 596°C, and 670°C. At the latter three temperatures, samples suffered severe breakage and extensive cracking. All other samples appeared sound and exhibited a gradual transition from yellow to red with increasing temperature. The 100°C, 150°C and 200°C specimens exhibited a progressively darker yellow coloration, the 250°C and 316°C samples were distinctly reddish with only an occasional very dark yellow area, and the samples heated to 380°C, 486°C, and above became a dark red, approximately Munsell 5R 3/4 (Munsell 1946). It is evident that the yellow-to-red color change can easily be achieved by a low-temperature heat treatment of moderate duration—conditions readily available near an aboriginal campfire.

In order to understand the nature of the yellow-to-red color change, X-ray diffraction patterns were obtained for unheated yellow and thermally altered red specimens. The latter was equilibrated in air for 24 hours at 400°C to ensure complete alteration as noted for heat treatment test 2. Powder diffraction methods using a Rigaku Giegerflex diffractometer with a graphite crystal monochromator were employed. The X-ray diffraction analysis of the yellow jasper revealed two readily identifiable phases—alpha-quartz, SiO_2, (JCPDS, 5-0490 [1978a]) and poorly crystallized goethite, ($FeO{\cdot}OH$), or $1/2(Fe_2O_3{\cdot}H_2O)$, (JCPDS, 17-536 [1978b]). Dana and Dana (1962) discuss the presence of goethite in yellow jaspers. X-ray diffraction of the thermally altered red jasper, after the 24-hour heat treatment at 400°C in air, again revealed the presence of alpha-quartz, but instead of the goethite, well-crystallized alpha hematite, Fe_2O_3 (JCPDS, 13-534 [1978c]), was present. It is evident that the thermal treatment of Bald Eagle Jasper produces the yellow-to-red color change as a result of the decomposition of the jasper's iron-containing component from goethite to hematite, according to the reaction:

$$2(FeO{\cdot}OH) \rightarrow Fe_2O_3 + H_2O(g)\uparrow. \quad (1)$$

This reaction has been extensively studied by Froncombe and Rooksby (1959). Klippel (1970) has also reported it during the heating of Burlington chert.

Additional insights into the goethite-hematite reaction, (equation 1), result from the comparison of the expected and observed Fe_2O_3 and H_2O contents of the altered and unaltered samples. The total hematite (Fe_2O_3) content was analyzed using the technique of stannous chloride reduction followed by potassium dichromate titration. Water content was analyzed as two portions: (i) the "minus" water, or moisture lost after 24 hours at 105°C in a vacuum oven, and (ii) the chemically combined water as determined by a modified Penfield method. The chemically combined water content was found to be 2.23%. If it is assumed that all of this water is in the goethite, then the red thermally altered jasper should contain (162/18) × (2.23), or 20.1% Fe_2O_3, according to equation (1). Equilibrated at 400°C for 24 hours in air, the red jasper was analyzed to contain 17.8% Fe_2O_3, reasonably close to the theoretical value. Considering that minor amounts of clays may also be present in jasper, as discussed by Dana and Dana (1962), or some Al^{+3} substituted for the Fe^{+3} as noted by Mendelovici et al. (1979), the agreement is satisfactory. The "minus" water, or water adsorbed was only 0.23%, comparable to that observed in some raw flints by Weymouth and Williamson (1951).

Further confirmation that goethite decomposition is the basis for the yellow-to-red color change was sought through thermal gravimetric analysis (TGA) and differential thermal analysis (DTA) on crushed yellow Bald Eagle Jasper heated at 5°C per minute. In Figure 2, the TGA revealed rapid weight loss in the temperature range 200°C to 300°C. As previously noted, this corresponds to the range at which the yellow jasper changed to red. Although Derr et al. (1967) report that well-crystallized goethite decomposes between 350°C and 390°C, Mackenzie (1957) illustrated that poorly crystallized material decomposes at somewhat lower temperatures, and Dasgupta (1955) reports that the presence of silica still further lowers the decomposition temperature. Since Bald Eagle Jasper is nearly 80% silica, the maximum rate of weight loss between 200°C and 300°C, as revealed by the TGA, is consistent with the presence of poorly crystallized goethite in a silica base mineral.

The DTA results are also consistent with the goethite to hematite decomposition. Figure 3 indicates two rather broad peaks: the first represents the loss of the "minus" water in the general vicinity of 100°C, while the second (an endothermic peak around 285°C that encompasses the range 225°C to 315°C) corresponds to the goethite to hematite decomposition. Thus, both the TGA and the DTA analyses confirm that the yellow-to-red transition in Bald Eagle Jasper results from the decomposition of goethite to hematite.

Since the thermal alteration of jasper near an aboriginal campfire may take place in a reducing atmosphere, as opposed to the oxidizing environment of air, it was decided also to examine the jasper's alteration under highly reducing conditions. Dry hydrogen was chosen as the atmosphere for heat treatment (3), a 24-hour heat treatment at 275°C, as suggested by the TGA and DTA results of Figures 2 and 3. The yellow-to-red color change was identical to that in air, and the weight loss of 2.58% was in satisfactory agreement with the 2.46% (2.23 + 0.23) observed for the 24-hour, 400°C heat treatment in air. The X-ray diffraction pattern also revealed quartz and hematite to be present, again similar to the air heat treatments. It is evident that the dehydration reaction described by equation (1) is not sensitive to the oxidizing/reducing conditions of the atmosphere in the temperature range of the yellow-to-red transition of the jasper.

The final series of heat treatments, (4), consisted of rapidly exposing cubes similar to those in

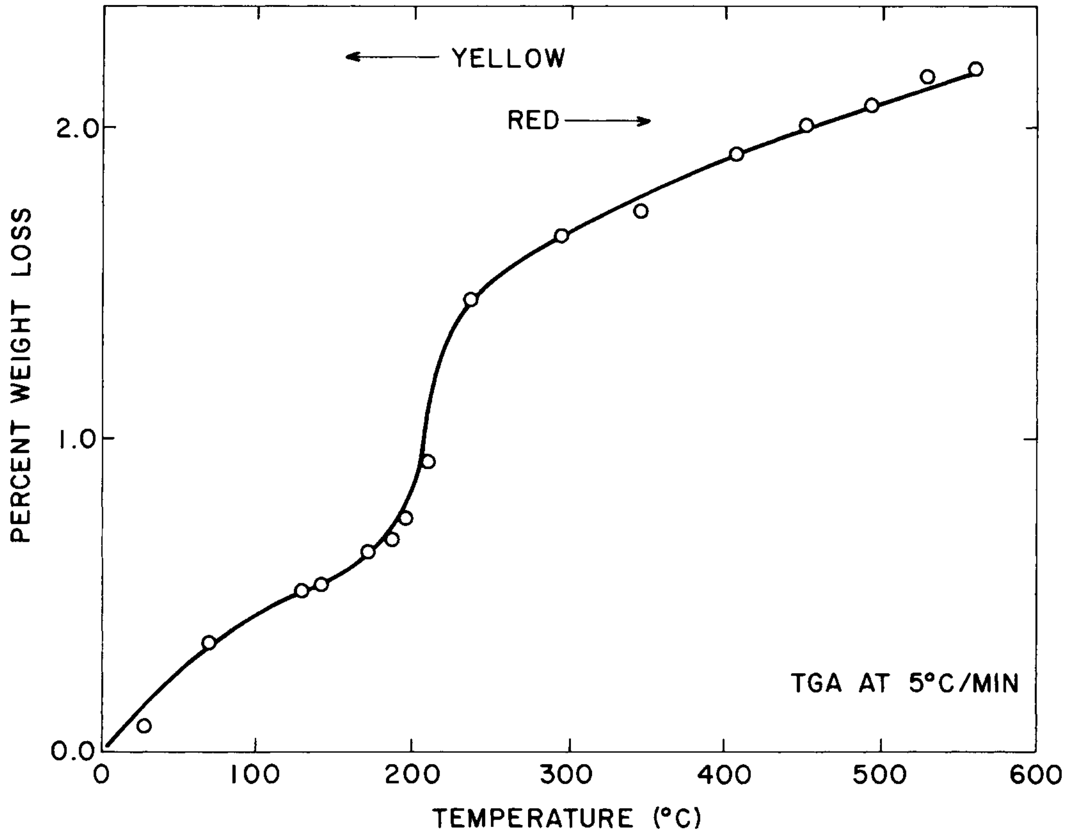

Figure 2. Thermogravimetric analysis (TGA) of the Bald Eagle Jasper. Note the temperature range (200°C–300°C) of the maximum rate of weight loss and its correspondence with the yellow-to-red transition.

the first series of heat treatments to elevated temperatures for short exposures. These were designed to simulate the exposure of jasper surfaces to heat from a campfire. After these elevated temperature treatments, the cubes were sectioned to observe the interior cores as well as the exterior surfaces. Specimens exposed to temperatures in excess of 300°C frequently exhibited a reddened exterior surface surrounding a yellow, unaltered interior core. The thickness of the reddened surface layer increased with the temperature and the duration of exposure. Obviously, the exterior was sufficiently heated to effect the goethite-to-hematite transformation in the near-surface region, while the interior core was unaffected. It is evident that the thermal alteration process can be achieved at specific surface regions when heat is applied here. One can readily envision altering only regions desired to be flaked away by locally heating the stone.

The specific mechanism of the yellow-to-red color change during the decomposition is not well understood. The iron cation is in the plus three valence state in both structures, so that the color change must be related to the (OH^-) and (O^{-2}) interaction with the Fe^{+3}). William B. White (personal communication) suggests that the yellow-to-red color change may be simply the result of replacing (OH^-) with (O^{-2}) in the coordination polyhedra of the (Fe^{+3}) cations.

In examining the yellow and the red jaspers by X-ray diffraction, we observed numerous lines of alpha-quartz, which are readily identified in the pattern. These quartz lines were always distinct and sharp in both the yellow and red jaspers, and showed no indication of any shift or broadening after the 400°C thermal treatment. No noticeable change in the quartz was seen in petrographic thin sections or in scanning electron microscopy. These observations are in complete agreement with those of Purdy and Brooks (1971) and Tullis (1970) who found that thermal

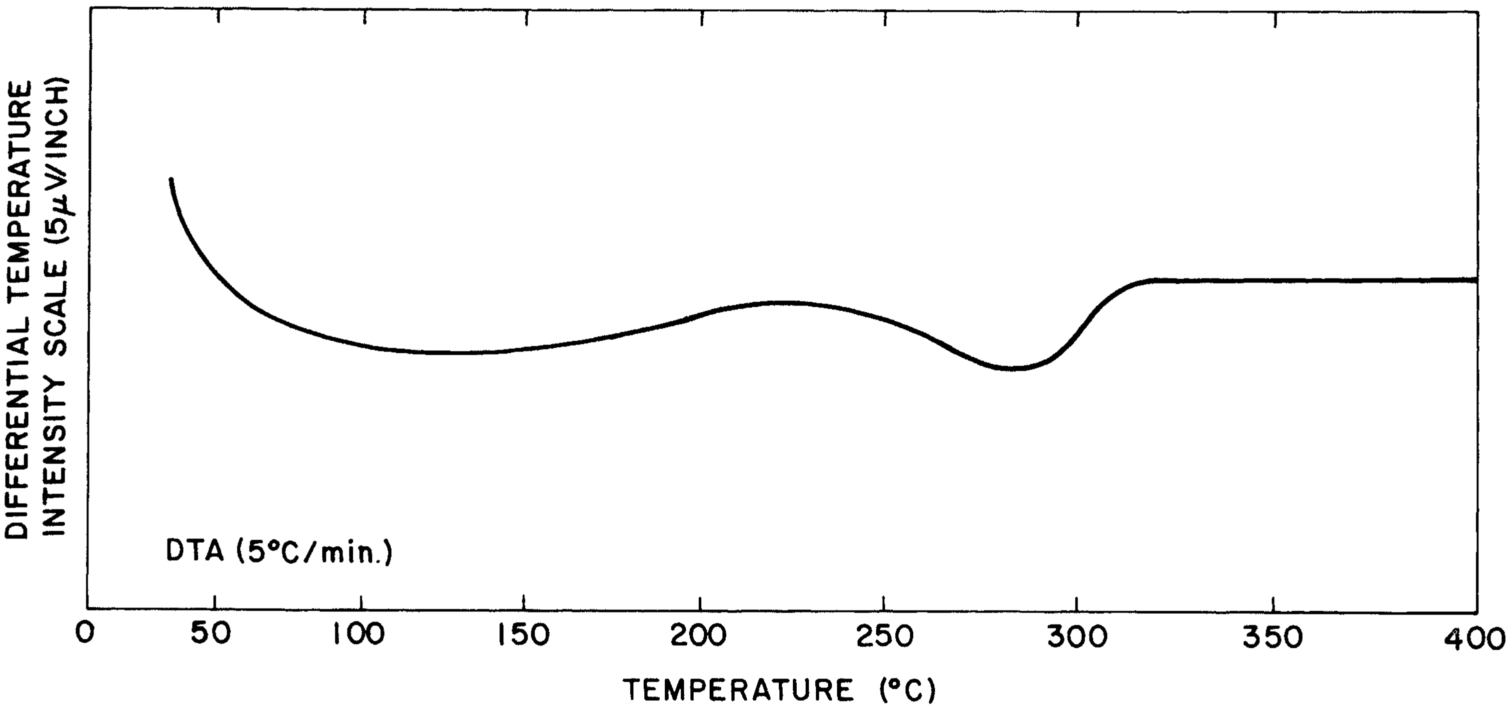

Figure 3. Differential thermal analysis (DTA) of the Bald Eagle Jasper. Note the loss of "minus" water about 100°C and the goethite decomposition (200°C–300°C).

alteration processes do not appear to affect the quartz in siliceous minerals. They do not in Bald Eagle Jasper.

Change in Working Characteristics

To understand the role of thermal alteration in the prehistoric use of Bald Eagle Jasper, it is essential to document a direct association between the color change and an improved workability of the stone. During the mortar and pestle grinding of the yellow and red specimens for the X-ray diffraction analysis, it was obvious that the heat-treated red jasper was more readily crushed and ground than the yellow untreated jasper. Unfortunately, neither crushing nor mortar and pestle grinding are readily amenable to a quantitative description. A well defined mechanical measurement is required. Various strength parameters such as compressive strength and tensile strength have been employed by other investigators. However, simple strength measurements may be misleading since they are highly dependent on the surface condition at the point of fracture initiation. For example, highly polished surfaces yield higher strengths than scratched surfaces. As illustrated by Lawn and Wilshaw (1975), the most fundamental parameter to measure for a quantification of the resistance to fracture is fracture toughness, K_C. Fracture toughness is a material constant, a measure of the material's resistance to crack propagation. Higher K_C's indicate a greater resistance to fracture. For example, Hertzberg (1976) reports that a typical window glass has a K_C of about 0.7 $MNm^{-3/2}$, whereas a tough maraging steel could be greater than 200 $MNm^{-3/2}$.

The specimens from the systematic heat treatment in the thermal gradient furnace were mounted in epoxy, polished with successively finer grit SiC abrasives through 600 mesh, and then given a final polish using a suspension of 0.3 μm Al_2O_3 in water on a rotating polishing wheel. The fracture toughness, K_C, was then measured using the micro-indentation flaw-extension technique as discussed by Evans and Charles (1976) and by Warren (1978). In applying this method, a Vickers microhardness indentation was made in the polished surface, and the fracture toughness was determined from the indentation size and the lengths of the cracks emanating from the indent corners. Five indentations were made on each of the heated samples and on a single unheated specimen. Average K_C values with 95% confidence limits defined by the "t" distribution were then computed.

The results presented in Figure 4 show a distinct decrease in K_C with increasing temperature of heat treatment. The curve exhibits the decrease in precisely the region of goethite-to-hematite decomposition and the yellow-to-red color change. The unheated yellow Bald Eagle Jasper is nearly twice as tough as the thermally altered red jasper. It can, therefore, be concluded that the heat treatment decreases the Bald Eagle Jasper's resistance to fracture to about one-half of its original value.

In order to further verify that the yellow-to-red transition occurs during the decomposition of goethite to hematite and that the decomposition is in fact responsible for the decrease in fracture toughness, a scanning electron microscopic analysis of both heated and unheated samples was performed. Figure 5 compares the fracture surfaces of the yellow Bald Eagle Jasper and the red, thermally altered jasper. There is little evidence of structure in the unheated yellow Bald Eagle Jasper; however, the heat-treated red jasper sample exhibits distinct "channels" throughout its structure. The large flat regions between the "channels" are the alpha-quartz. The "channels" are filled with well defined hematite crystals, resulting from the goethite decomposition to hematite. Figure 6 shows one of the "channels" at a higher magnification. It clearly reveals the presence of well formed hematite crystals. A KEVEX analysis of one of these crystals demonstrated a composition dominated by iron (Fe), with traces of nickel (Ni) and copper (Cu). The distinct polyhedral shapes of the hematite crystals are obvious. Some large cracks between these crystals and the alpha-quartz material are also evident.

It can be concluded that the structure of the yellow Bald Eagle Jasper consists of regions of alpha-quartz "bound" together by goethite. Thermal alteration in the temperature range of 200°C to 300°C decomposes the goethite to hematite, leaving a structure of hematite crystals between

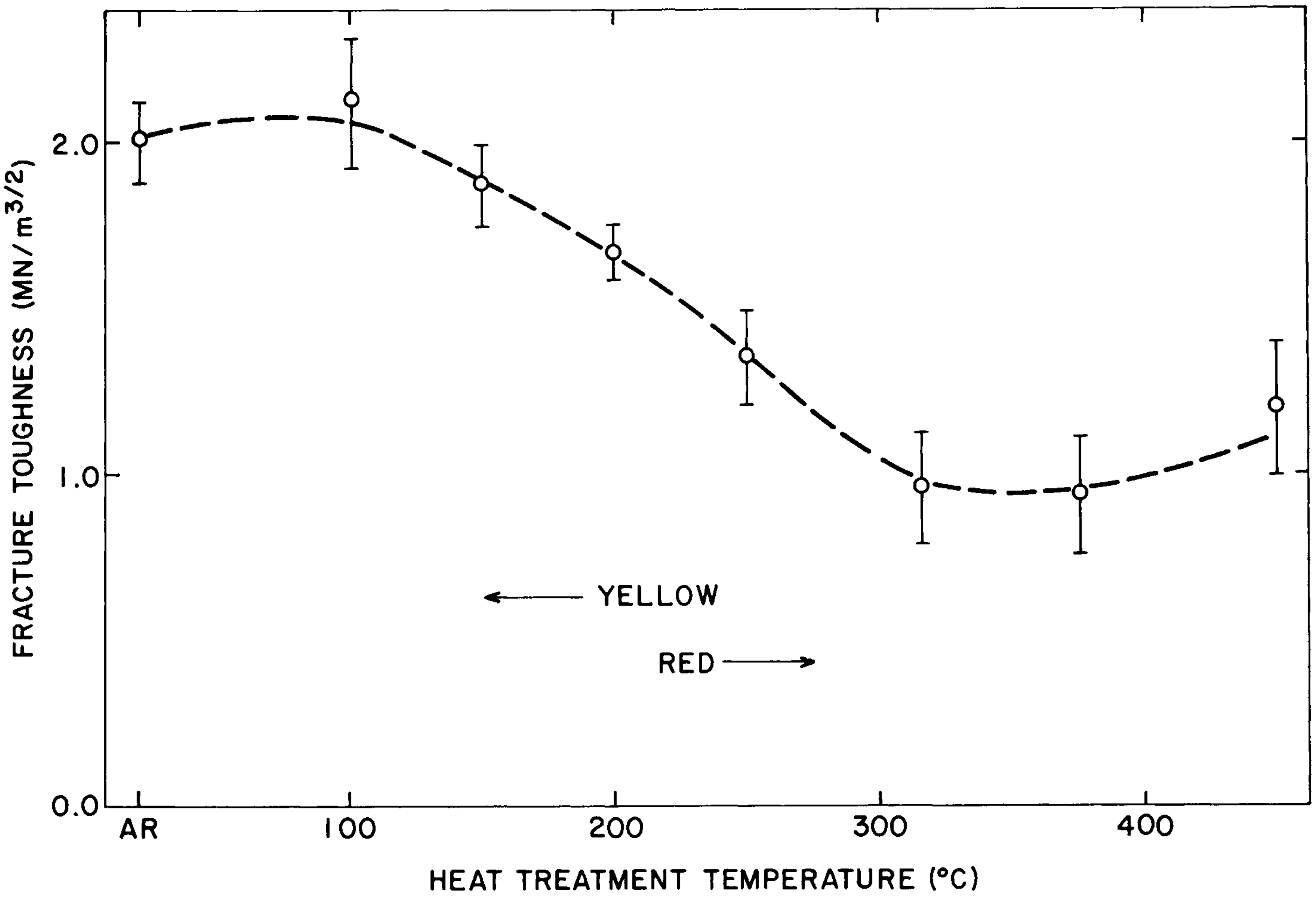

Figure 4. The effect of heat treatment temperature on the fracture toughness of Bald Eagle Jasper. AR designates the as-received yellow jasper.

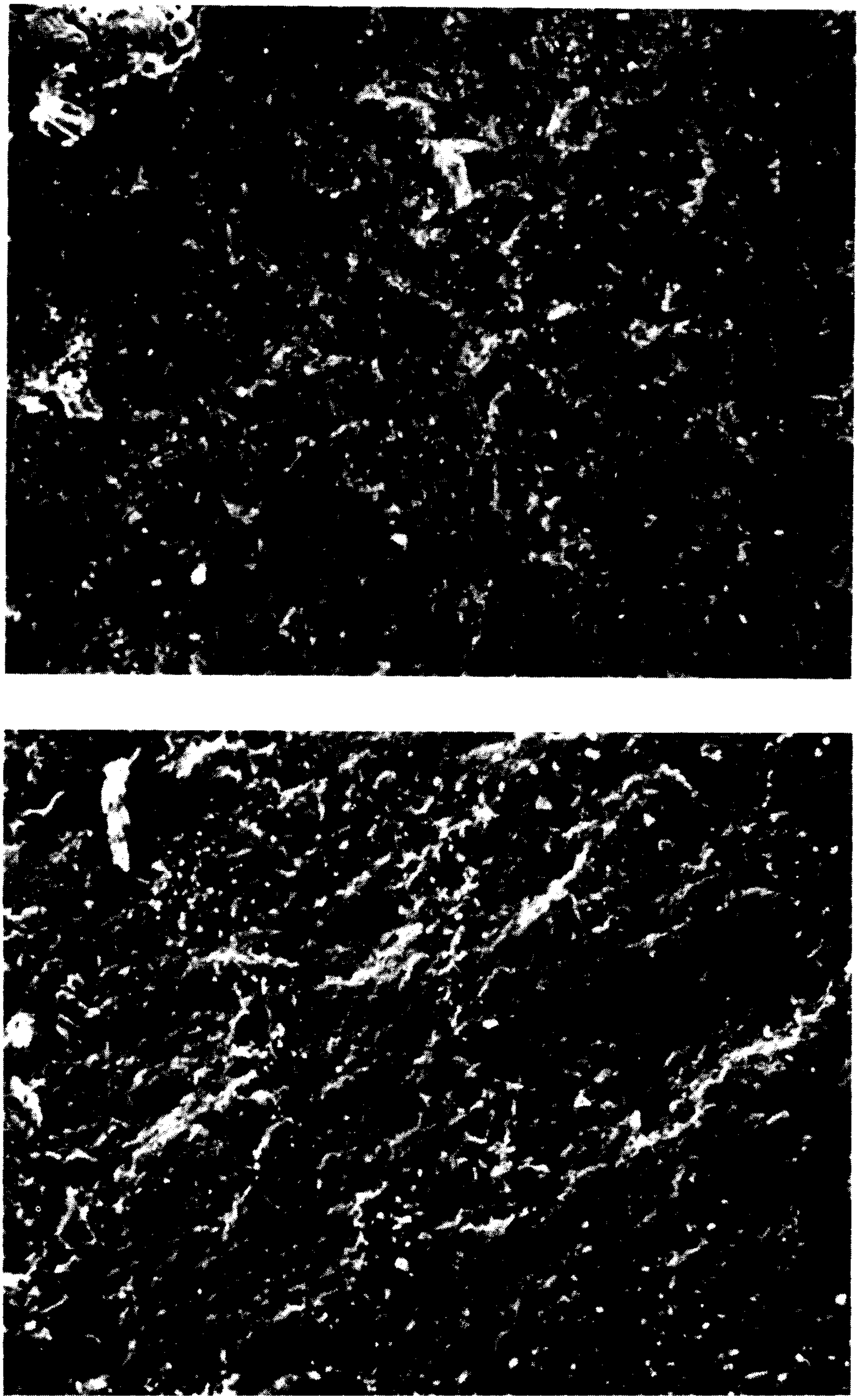

Figure 5. Scanning electron micrographs of fracture surfaces at 100x of the as-received yellow jasper (A) and the 400°C thermally treated red jasper (B). Note the "channels" in the thermally altered red jasper (B).

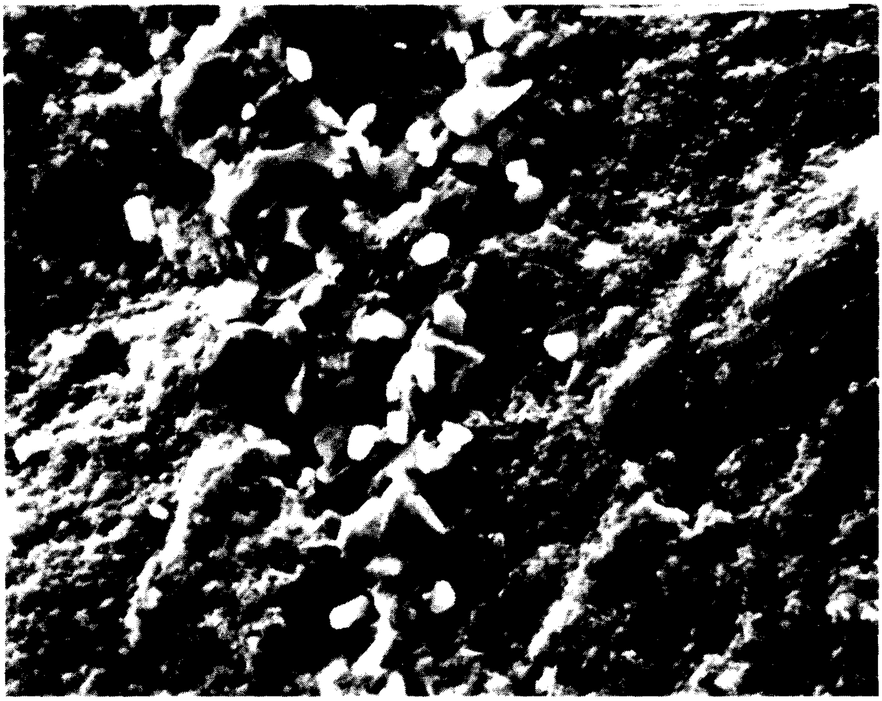

Figure 6. A 20,000x magnification of the "channels" containing hematite in thermally altered red jasper. Note the well defined crystal facets and the microcracks between the hematite crystals and the very fine-textured quartz.

the alpha-quartz regions in what is now a red jasper. These hematite crystals are extensively microcracked away from the quartz and to some extent are microcracked away from one another. It is the presence of these weak microcracked hematite "channels" that causes the decreased fracture toughness and the increased workability of the red jasper. The cause of these microcracks is evident if the densities of goethite and hematite are considered. Goethite has a density of 4.26g/cm^3, while hematite is 5.28 g/cm^3. Since there is little alteration in specimen dimensions during thermal alteration, goethite decomposition leaves about 25.7% void space. This takes the form of microcracks between the hematite crystals themselves and between the hematite crystals and the alpha-quartz regions, thus weakening the jasper and improving its ease of fracture. From the stoneknapper's perspective, increasing the material's ease of fracture improves its workability.

A number of investigators have noted that fracture surfaces of thermally altered cherts characteristically appear more lustrous than those of untreated material. This is also the case for Bald Eagle Jasper and is probably a result of an increase in the reflection of light from the well-defined facets of the hematite crystals in the "channels" of the red jasper (Figure 6). Although the "channels" comprise only a small fraction of the total surface, their fineness and proximity to each other cannot be discerned without instrumental assistance. Thus, observation with the unaided eye results in a uniformly increased lustrous appearance.

LITHIC TECHNOLOGY AT THE HOUSERVILLE SITE

To fully understand the role of thermal alteration in the prehistoric use of Bald Eagle Jasper, we must examine the use of heat treatment in the lithic technology employed in the exploitation of this resource. An analysis of the byproducts of core reduction at the Houserville Site, a primary jasper procurement and tool manufacturing location, provides important insights into this relationship.

When compared with lithic samples from neighboring sites, the Houserville assemblage exhibits several distinctive characteristics. First, percussion-struck biface thinning flakes are the numerically dominant form of debitage. Large, cortical flakes are also present, but in lower frequencies. In contrast, the small, pressure-produced biface thinning flakes found on many sites in the region are virtually absent. Failed biface preforms, which range from minimally worked, large, irregular specimens to small, thin, finely worked ones are the artifacts most frequently found at Houserville. Finished tools such as projectile points and end-scrapers do occur, but they are far less common than preforms. While Bald Eagle Jasper comprises 99% of all preforms and debitage at the Houserville Site, only 47% of the finished tools are made from this material. The remainder are manufactured from a wide variety of lithic materials available in the surrounding region.

The predominance of broken preforms and percussion-struck biface thinning flakes coupled with the absence of pressure flakes suggests that lithic manufacture at the Houserville Site was primarily directed towards the production of preforms rather than finished tools. Presumably, these preforms were transported to habitation sites in the neighboring area where they were used for the production of projectile points. This notion is largely confirmed by the lithic assemblages from these habitation sites, which are dominated by small, pressure-produced biface thinning flakes and finished or nearly finished projectile points (e.g., Webster et al. 1977).

It is evident that heat treatment played a vital role in the technology of preform manufacture at Houserville, since numerous specimens in each of the lithic categories described above exhibit partial or complete red coloration. It is also clear that the relative proportions of these heat-treated specimens vary considerably from one lithic category to another. However, the specific role of thermal alteration in the manufacture of the Houserville preforms can only be understood by examining this variation within the context of the core reduction strategy that was used in the exploitation of Bald Eagle Jasper.

The Houserville core reduction sequence was reconstructed using previous knapping investigations as a guide, including those of Bradley (1975), Collins (1975), Ellis (1940), Holmes (1891), Knowles (1953), and Mewhinney (1957). This reconstruction was based on the assumption that the primary activity represented by the Houserville assemblage was the manufacture of finely worked biface preforms. It was further assumed that these preforms were manufactured from nodular raw material through a process of increasingly well controlled biface thinning. Both of these assumptions are supported by the general character of the Houserville assemblage.

The analysis of the Houserville core reduction sequence relied on samples of materials from a series of surface-vacuuming collections of the site. Preliminary analyses of excavated materials from Houserville confirm the representativeness of these samples. The preforms in the Houserville assemblage can be subdivided into three categories on the basis of the degree of thinning and regularity of outline: (a) crude preforms, (b) intermediate preforms, and (c) fine preforms. The flakes in the assemblage were grouped into categories corresponding to these preform classes: (i) primary trimming flakes, (ii) crude biface thinning flakes, and (iii) intermediate biface thinning flakes.

Primary trimming flakes show evidence of removal during the initial manufacturing stage, when crude preforms were being fashioned from nodules of raw material. Crude biface thinning flakes are relatively large and thick, but exhibit unmistakable evidence of having been removed from a biface; previous flake removal scars on exterior surfaces, faceted platforms, and relatively small angles between platform surface and flake axes are common attributes. Flakes belonging to this category were presumably produced during the manufacture of the thinner, more regular preforms classified as intermediate preforms. Intermediate biface thinning flakes are thin, regular flakes showing all the characteristics of classic biface thinning flakes. These attributes consist of complex patterns of previous flake removal scars on exterior surfaces, faceted platforms showing evidence of "scrubbing" prior to flake removal, and small angles between platforms and flake axes. It can be assumed that these flakes were struck during the final stages of preform manufacture, when intermediate preforms were being further thinned and shaped to produce a fine or finished preform. The relationships between the preform types, the flake types, and the manufacturing activities of this classification are summarized schematically in Figure 7.

Using these categories, the Houserville assemblage was further classified on the basis of evidence for heat treating, i.e., partial or complete reddening. The results of this classification are summarized in Table 1. This table has important implications concerning the nature of tool manufacture at the Houserville Site, including the role of heat treatment in the manufacturing process and the success rate of Houserville knappers in producing finished preforms.

The role of heat treatment in the Houserville manufacturing sequence can be inferred from the relative proportions of heated and unheated specimens in the several lithic categories. For example, 42% of the primary trimming flakes exhibit clear evidence of having been heat treated (Table 1). Since flakes of this type were struck from nodular raw material during the initial manufacturing stage, it can be assumed that some Bald Eagle Jasper nodules were heat treated prior to primary flaking. On the other hand, 58% of the primary trimming flakes exhibit no evidence of prior heat treatment, suggesting that it may have been equally common to proceed with initial core reduction flaking prior to the application of heat treatment. The decision to heat treat the material may have depended on the knapper's perception of the character of the nodule.

The relative proportion of heat-treated specimens increases rapidly when one moves from the initial stage of nodule trimming to the subsequent bifacial thinning stages. Of the crude biface thinning flakes 84% exhibit clear evidence of heat treatment. Since these flakes were removed from crude biface preforms, it must be concluded that almost all such preforms were heat treated prior to further bifacial thinning. However, only 55% of all crude preforms, the source of crude biface thinning flakes, exhibit direct evidence of heat treating. In a similar fashion, 80% of the intermediate biface thinning flakes show evidence of heat treatment, while only 47% of intermediate biface preforms exhibit such evidence.

These data reveal the sequence of the manufacturing process. High percentages of reddened biface thinning flakes suggest that the majority of both crude and intermediate biface preforms were heat treated prior to further thinning. The preforms themselves, however, exhibit a much lower incidence of reddening, which would seem to indicate that heat treatment was only occasionally applied. This apparent discrepancy can be explained, however, by assuming that two processes were characteristic of the Houserville core reduction sequence. First, preforms must have been only partially altered on the surface by the heat treatment process, thus producing a reddened exterior layer while leaving a yellow, unaltered core. The reddened, more easily worked exterior was then flaked away during the subsequent core reduction stage. Most of the flakes produced by this process would exhibit evidence of heat treatment, while the resulting, more nearly completed preform would frequently consist of yellow unaltered jasper. Second, preforms must have been heated repeatedly during the manufacturing process. After each heating episode, the reddened surface layer was flaked away; if the resulting preform was suitable for further reduction, it was generally reheated. If, on the other hand, a core failed or was otherwise considered unsuitable, it would be discarded without further applications of heat. These processes produced populations of biface thinning flakes composed primarily of reddened specimens; at the same time, however, they also produced populations of preforms that were discarded after an unsuccessful attempt at bifacial thinning, but prior to any subsequent heating episode. As a result, they show a higher percentage of unaltered yellow pieces.

It is evident that failure was a common event throughout the manufacturing process represented by the Houserville assemblage. Preforms generally exhibit one or more of three common flaws: (a) transverse breakage, (b) protuberances suggesting unsuccessful bifacial thinning, and (c) pot-lid type fractures, presumably resulting from improper heat treating. These flaws are exhibited by preforms at all stages of manufacture; however, failed preforms at the earlier core reduction stages clearly outnumber those in the latter stages. For example, Table 1 reveals that the ratio of failed crude preforms to failed fine preforms is 4:1, indicating that several attempts at core reduction were required to produce a single finished preform. Since many of these latter

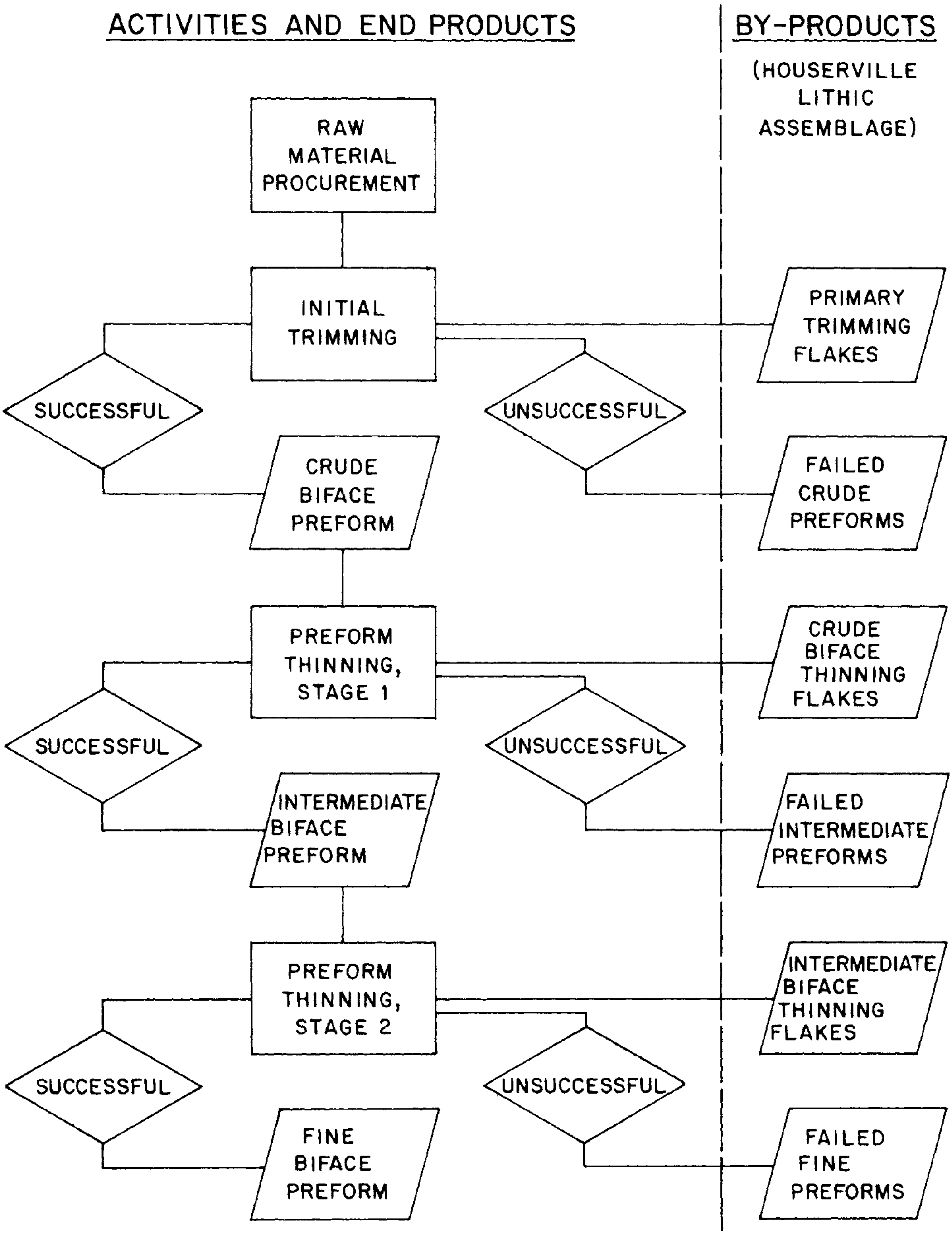

Figure 7. The Core Reduction Sequence used at the Houserville Site (36Ce65).

Table 1. Heat Treated vs. Untreated Specimens by Lithic Category.

Lithic Category	Unheat-Treated*	Heat Treated*	Totals
(a) Crude biface preforms	9 (45%)	11 (55%)	20
(b) Intermediate biface preforms	8 (53%)	7 (47%)	15
(c) Fine biface preforms	2 (40%)	3 (60%)	5
(i) Primary trimming flakes	19 (58%)	14 (42%)	33
(ii) Crude biface thinning flakes	23 (16%)	123 (84%)	146
(iii) Intermediate biface thinning flakes	110 (20%)	431 (80%)	538

* Without any indications of reddening.

** Visible reddening on surface.

preforms undoubtedly failed during final modification into finished tools, an even higher ratio of unsuccessful to successful attempts at tool production can be inferred.

The repeated application of heat treatment and the high rate of failure exhibited by the Houserville assemblage indicate that a labor-intensive lithic technology was required in the exploitation of Bald Eagle Jasper. On the average, each finished tool required numerous attempts at core reduction, and many of these attempts involved one or more applications of heat treatment. The amount of labor invested in the production of a single projectile point thus appears to have been relatively large.

REGIONAL IMPLICATIONS OF BALD EAGLE JASPER EXPLOITATION

The results of an intensive survey of 57 km^2 of the Bald Eagle Creek watershed carried out concurrently with excavations at the Houserville Site provide a basis for evaluating the role of Bald Eagle Jasper exploitation in regional tool production. Lithic materials from 148 sites, many with both surface and subsurface collections, were used to evaluate period-specific preferences for raw material types. In addition, the spatial implications of debitage distributions were assessed for various models of local social organization.

Although Bald Eagle Jasper flakes and tools are common in the lithic samples recovered from sites in the Bald Eagle Creek watershed, several other materials are also represented. Black flint, rhyolites, several types of chert, quartz, and argillite also occur. To identify regional variations in the use of these raw material types, the relative frequencies of each were tabulated for all of the sites in the survey that produced 100 or more lithic specimens. These sites were then plotted on a three-coordinate graph, using percentages of the three most common lithic raw material types as variables. Figure 8 illustrates the three distinct clusters produced by this procedure. One cluster includes sites with lithic samples consisting almost exclusively of Bald Eagle Jasper, one includes those that are predominantly black flint, and the third includes sites with high percentages of gray cherts. The remaining lithic types are present in small quantities at many of the sites but do not exhibit numerical dominance in any. The pattern evident in Figure 7 indicates that a tripartite classification of sites is appropriate and that hypotheses concerning these debitage distributions can then be tested. These tests provide insights into the role of Bald Eagle Jasper exploitation in the prehistoric lithic technologies of the Bald Eagle Creek Watershed.

Three procedures were employed to evaluate Bald Eagle Jasper debitage distributions. First, in order to reveal chronological changes in raw material preference, the lithic materials of all temporally diagnostic projectile points were identified. Second, the associations of diagnostic projectile points with sites exhibiting a predominance of Bald Eagle Jasper were analyzed. Third, the spatial distributions of these sites were examined with respect to known sources of raw material.

Table 2 presents the phase-specific associations of the projectile points discovered during the survey. By examining the lithic material from which these points were manufactured, we iden-

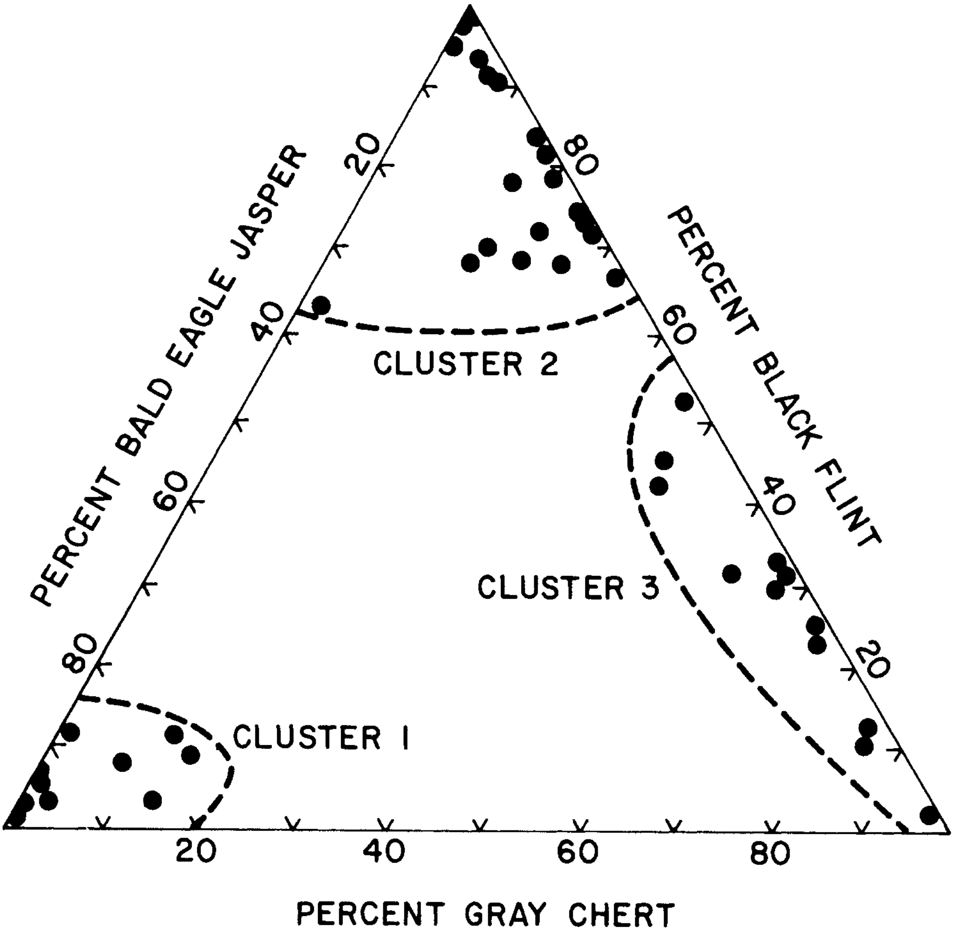

Figure 8. Raw Material Preference Clusters in the Bald Eagle Creek Watershed.

tified changes in lithic procurement practices. The results (Table 3) indicate a clear preference for black flint during Late Woodland times, and only during Late Woodland times. This suggests that the distribution of black flint within the survey zone may relate primarily to a Late Woodland settlement pattern. In contrast, raw material preferences for all earlier periods are less obvious. Many different raw materials were used in the manufacture of projectile points. Of primary significance for the present analysis, however, is an apparent clustering of Bald Eagle Jasper points in the Early and Middle Archaic periods. Although sample sizes are small, this clustering suggests that Bald Eagle Jasper utilization was primarily an Early and Middle Archaic phenomenon.

The predominantly Early-Middle Archaic utilization of Bald Eagle Jasper was confirmed by a second test, which involved analyzing the associations of diagnostic projectile points with the sites included in each cluster. Regardless of the material from which they were made, 65% of all diagnostic points found on Bald Eagle Jasper sites are of Early and Middle Archaic styles. It therefore appears that the distribution of Bald Eagle Jasper debitage within the survey area is primarily a function of Early and Middle Archaic settlement patterns. Similarly, 68% of all diagnostic points found on black flint sites are of Late Woodland styles, confirming the hypothesis that the distribution of black flint debitage relates primarily to Late Woodland raw material procurement and transport activities.

Table 2. Projectile Point Type Chronological Assignments and Frequencies of Occurrence.*

Period	Type	Number
Late Woodland	Shenk's Ferry, Susquehannock, Other Triangular Points	37
Middle Woodland	Snyders, Jacks Reef	4
Early Woodland	Meadowood, Rossville	2
Transitional	Susquehanna Broad Spear	3
Late Archaic	Genesse, Snook Kill, Sylvan Side Notched, Sylvan Stemmed, Brewerton	19
Middle Archaic	Otter Creek, Raystown Stemmed	6
Early Archaic	Palmer, Kirk, MacCorkle	10
Nondiagnostic		18
Total		99

* Based on Funk (1976), Bebrich (1971), Coe (1964), Broyles (1971), Turnbaugh (1977), Ritchie (1961), Ritchie and Funk (1973), Calkin and Miller (1977), and Brennan (1977).

In a final test, the distribution of sites was compared to known raw material source localities. The results of this comparison indicate that sites that show a predominance of black flint are widely scattered and are found in the vicinity of both black flint and Bald Eagle Jasper outcrops. They are most often situated adjacent to high quality agricultural soils, indicative of the well known Late Woodland economy based on maize, beans, wild grass seeds, nuts, and deer. This pattern suggests that the distribution of black flint within the survey zone is not primarily a function of proximity to sources but is instead a result of Late Woodland raw material preferences. In contrast, the sites where Bald Eagle Jasper dominates showed a tight clustering around the Houserville outcrop. About 80% of these sites were located within the same 2.6 km^2 survey unit as the Houserville Site, and those that fell beyond reflect little more than single resharpening events at hunting camps and blinds. This latter pattern suggests that proximity to lithic source was an important determinant of procurement strategy during Early and Middle Archaic times. In conjunction with the wider range of materials used for projectile point manufacture, it also suggests that eclectic use of raw materials was characteristic of the Early and Middle Archaic periods.

The patterns that emerge from these analyses have important implications for prehistoric social organization in the Bald Eagle Creek watershed. Clear differences in the distributional patterns of Bald Eagle Jasper and black flint tools and debitage have been revealed, which probably relate to differences in the lithic procurement and production strategies of the Early and Middle Archaic as compared to the Late Woodland inhabitants of the watershed. In turn, these differences in lithic technology probably reflect more general differences in economic and social organization. In ways that are not yet fully understood, the Late Woodland focus on a single lithic

Table 3. Projectile Point Raw Material and Frequency of Occurrence by Period.

Period	BE-Jasper	Black Flint	Grey Chert	Others
Late Woodland	0	27	5	5
Middle Woodland	1	0	0	3
Early Woodland	0	0	1	1
Transitional	1	1	1	0
Late Archaic	0	3	7	9
Middle Archaic	4	0	1	1
Early Archaic	1	0	3	6
Totals	7	31	18	25

raw material and the consequent dispersal of that material over a wide area may reflect aspects of the relatively large, sedentary, agricultural societies that are presumed to characterize this period (Hay 1980). In contrast, the Early and Middle Archaic pattern, in which many raw materials were exploited, probably reflects a more mobile way of life.

During Early and Middle Archaic times, the Houserville Site witnessed repeated visits for the purpose of procuring and manufacturing Bald Eagle Jasper biface preforms. As indicated by the presence of Early and Middle Archaic projectile points and end-scrapers in the Houserville assemblage, the groups that visited the site probably resided there while engaged in procurement and core reduction activities. It seems likely that the presence of the Bald Eagle Jasper outcrop had a strong influence on the selection of the Houserville Site as a camping place. However, the presence of end-scrapers and finished projectile points in the assemblage, which were probably either lost or discarded during use, suggests that hunting and the processing of hides may have been important economic activities as well.

Since these finished tools exhibit a wide variety of lithic raw materials it can also be assumed that the Early and Middle Archaic inhabitants of the Houserville Site did not rely exclusively upon Bald Eagle Jasper for the manufacture of their stone tools. Instead, they must have brought a curated lithic tool kit, made from various raw materials, to the site. During periods of residence, some of these tools were either lost or discarded, thus producing the distinctive character of the Houserville assemblage, in which the debitage is almost exclusively Bald Eagle Jasper, while the finished tools are of various raw materials.

These assemblage characteristics suggest that the Early and Middle Archaic inhabitants of the Houserville site had access to a large and ecologically diverse environment. They may have controlled large territories directly, or they may have gained access to widely dispersed resources through an extended network of kin ties. In either case, a form of social organization based on high mobility is implied. It seems likely that small groups of Early and Middle Archaic hunters and gatherers incorporated the jasper outcrop at Houserville into their patterned movements in order to prepare preforms that were converted into finished tools at other localities, as the need arose. These objects were carried by their makers throughout their territories and perhaps were traded beyond.

SUMMARY

Experimental analyses of Bald Eagle Jasper in conjunction with an examination of the jasper assemblage from the Houserville Site indicate that prehistoric populations in Central Pennsylvania systematically heat treated this material during biface preform manufacture. While unaltered Bald Eagle Jasper is yellow, it is reddened by the application of temperatures easily achieved near aboriginal campfires. The presence of reddened specimens representing various stages in the core reduction sequence of the Houserville assemblage thus suggested intentional thermal alteration. Laboratory experiments independently confirmed this hypothesis, clearly identifying the yellow-to-red color change as a result of the decomposition of the goethite component of Bald Eagle Jasper to hematite, and demonstrating that an increased ease of fracture is associated with this change. Analyses of the raw materials from which chronologically sensitive projectile points were manufactured indicate that Bald Eagle Jasper was exploited primarily during Early and Middle Archaic times. Examination of the areal distribution of Bald Eagle Jasper debitage revealed aspects of Early and Middle Archaic social organization and adaptive strategy.

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