Approaching the Hatch Jasper Quarry From a Technological Perspective: A Study of Prehistoric Stone Tool Production in Central Pennsylvania
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Approaching the Hatch Jasper Quarry From a Technological Perspective:
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ABSTRACT Mitigation of the Hatch jasper quarry, a "prospect site" in Central Pennsylvania, has enabled the reconstruction of a local system of stone tool acquisition and production. Artifacts from the quarry and the nearby Houserville habitation complex were analyzed using an attribute-based stage typology. This technological approach permitted the separation of geofacts from artifacts, and revealed evidence suggesting that Houserville knappers obtained tool stone from the quarry. Attention was also given to the study of how systematic heat treatment was used to enhance the flaking characteristics of the Hatch quarry jasper. This research highlights the benefits that a technological analysis of flake artifacts, in addition to finished tools, can provide for understanding stone tool production at quarry localities.

The reconstruction of ancient stone tool exchange and production has been an important and longstanding archaeological research priority (Adams 1966; Childe 1936, 1958; Ericson 1977a; Renfrew 1975; Torrence 1986). While considerable interest has been directed toward the study of lithic tool distribution, relatively little attention has been given to questions relating to its production in the northeastern United States. This article addresses the latter topic by looking at evidence for raw material acquisition and stone tool production at the Hatch quarry (36CE238) in central Pennsylvania (Figure 1).[1] This quarry is a source of Bald Eagle jasper that was used from the Late Archaic (3350 B.C.) to Late Woodland (A.D. 1500) periods.

The Hatch quarry is a *prospect site* (Wilke and Schroth 1989), a source where tool stone occurred as surface "float" material. Formal quarries, in contrast, have "quarry pits" indicating the prehistoric exposure of tool stone in primary bedrock contexts. At the Hatch quarry, Bald Eagle jasper occurs on the surface in the form of nodules and tablets. Although modern plowing and pasture management have altered much of the site's surface, test excavation and backhoe trenches did not reveal evidence of quarry pits or any deposits of jasper in primary context that would have promoted such investments (Murtha et al. 2001).

This research demonstrates the advantage of using technological analysis to examine quarry data and to understand them in the context of production. As earlier research has shown, such sites are valuable sources of information on prehistoric production processes (Ahler 1986; Ericson 1977b, 1981; Ericson

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and Purdy 1984; Flenniken 1993a, 1996a; Flenniken et al. 2001; Johnson 1984; Root 1997; Torrence 1986). Ericson (1984:1) suggested that quarries represent the logical place to begin reconstructing any system of stone tool production. Although this may be the case, quarry research can be intimidating because of the "shattered, overlapping, sometimes shallow, nondiagnostic, undatable, unattractive, redundant, and at times voluminous material record" (Ericson 1984:2). Much of this material consists of flake debitage. Over the last thirty years, approaches to debitage analysis have advanced considerably (Amick and Mauldin 1989, 1997; Andrefsky 1998; Apel 2001; Bradbury and Carr 1995, 1999; Flenniken 1981, 1984, 1987; Henry and Odell 1989; Morrow 1997; Patterson 1990; Prentiss 1998, 2001; Sullivan and Rozen 1985), but flakes are still generally understudied or ignored by most archaeologists (Fish 1981:375; Flenniken 1984:192; Shott 1994:70). Ignoring these data is unfortunate, because they represent the majority of stone artifacts ever produced and can provide a range of information about tool reduction activities, raw material availability and quality, knapping skill, specialization, and settlement and subsistence practices (Andrefsky 2001; Crabtree 1972; Flenniken 1984; Magne 1989:15, 2001; Nelson 1991; Pecora 1990, 2001; Rasic and Andrefsky 2001).

This study examines stone tool acquisition and production at the Hatch quarry, and how these activities were tied to jasper tool consumption at the nearby Houserville habitation complex. The Hatch quarry is located at the upper end of a shallow, broad drainage (Figure 2). It was mitigated because of plans to widen a road that had already impacted part of the site. This project

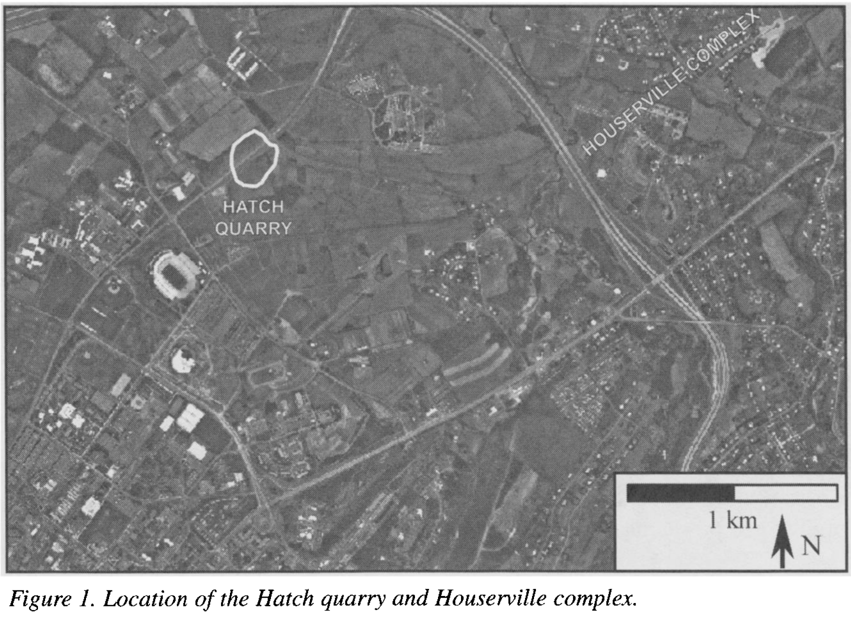

Figure 1. Location of the Hatch quarry and Houserville complex.

effectively destroyed the remaining cultural deposits at the quarry, prompting the recovery of a comprehensive artifact sample using intensive surface collection and limited excavation (Murtha et al. 2001).

Our analysis allowed us to accomplish three goals. First, we were able to distinguish geofacts from actual artifacts. This task is often relatively easy because of the unique characteristics associated with most isotropic stone. Bald Eagle jasper, however, is poor-quality material, some of which had been affected by frost fracture and surface burning. These processes created by-products that could be easily mistaken for artifacts. Second, using the technological classification developed by Jeffrey Flenniken (1987, 1989, 1993a), we were able to define a reduction sequence revealing the range of procurement and production behaviors at the quarry. Third, we conducted heat-treatment experiments to test earlier hypotheses about how this aspect of technology related to the toolmaking process (Shindler et al. 1982).

The Houserville habitation complex (Hatch and Miller 1986) is a zone of residential sites adjacent to Spring Creek, about 1.5 km east of the Hatch quarry (Figure 1). Flaked stone artifacts collected from these sites were predominantly made of Bald Eagle Jasper (Hay 1980:79–80; Hay and Stevenson 1984:69). Our analysis, based upon both the types of flakes and their percentages, and the point at which heat treatment was employed during reduction, demonstrates that jasper tool-producing activities at the Houserville complex and the Hatch quarry were linked. This is important because

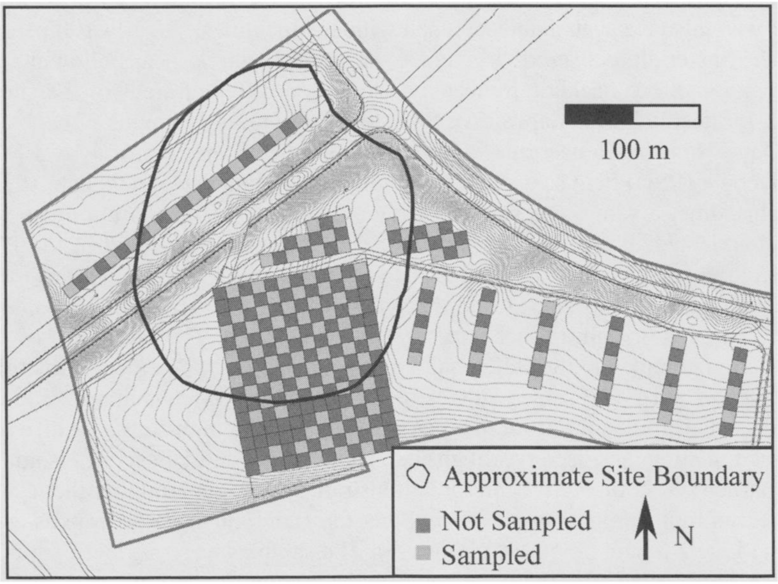

Figure 2. Spatial extent of the Hatch quarry and the location of the study sampling units.

information from behaviorally linked acquisition and consumption sites provides a fuller view of the entire production process, and contributes to the need for more comparative applications of lithic analysis (Magne 2001:24).

This discussion is divided into five major sections. The first reviews the data recovery strategies and the temporal affiliation of the Hatch quarry and Houserville complex. The next section describes the characteristics of Bald Eagle jasper, and the criteria used to separate the geofacts from artifacts. The third section reviews the system of classification applied to the debitage, and then describes the technological composition exhibited by both collections. The fourth section discusses how the heat-treatment experiments enhanced our understanding of the technology reflected by our debitage analysis. The results of the classification and heat treatment experiments are used in the final section to discuss our reconstruction of the Bald Eagle jasper reduction sequence.

Data Recovery Strategies and Chronological Affiliation

The Hatch quarry contains nodules, tablets, and flakes of Bald Eagle jasper scattered over a surface area of about 7 ha (Figure 2). Data recovery strategies consisted of both surface collection and excavation. Surface collections entailed hand-picking all suspected jasper artifacts from every other 10 x 10 m quadrant demarcated across the site (Figure 2). This strategy permitted coverage of more than 46 percent of the quarry surface area. Test pits measuring 0.5 x 0.5 m were excavated in 25 percent of the surface-collected quadrants; these materials were screened with 1/8-inch mesh. Around 15 percent of the site was then stripped of plow zone, exposing a few pit features that were also excavated and screened with 1/8-inch mesh. Nearly 100 percent of the material recovered was made of Bald Eagle jasper. Following the excavations, four backhoe trenches were dug on different areas of the site to look for deeply buried deposits of tool stone and cultural remains.

Data from the Houserville complex were collected by Pennsylvania State University (PSU) field school students who surveyed the area in the late 1970s. At that time, a sample of surface artifacts from several habitation areas was hand-collected. Both finished tools and debitage are represented in the PSU collection, but it is unclear whether data recovery was biased in favor of tools. It is probable that flakes from the small end of the spectrum are under-represented, since all artifacts were collected by hand. The proximity of this habitation complex to the Hatch quarry, and the fact that 95 percent of its lithic sample is Bald Eagle jasper, suggest that the Houserville inhabitants acquired most of their tool stone from the quarry. As we will demonstrate, the different collection strategies used to obtain the Hatch quarry and Houserville samples strengthen our comparative interpretations rather than undermining them.

Eleven radiocarbon samples reveal that the Hatch quarry was used as early as the Late Archaic (3350 B.C.; Figure 3). The samples were retrieved from pit features excavated after the plow zone had been removed from the site surface. These features contained substantial amounts of carbon, and probably represent the remains of heat treatment facilities (Murtha et al. 2001). Heat treatment played an important role in the reduction of Bald Eagle jasper. Even though the radiocarbon dates span a lengthy period of time, eight of them fall between 1000 B.C. and A.D. 500, indicating use of the quarry during the Early Woodland (1100 to 100 B.C.) and Middle Woodland (100 B.C. to A.D. 1000) periods (Figure 3). There are no radiocarbon dates for the Houserville complex, but projectile points recovered from the area indicate that this locality was used for a much longer period of time, beginning in the Early Archaic (9000 B.C.) and lasting until historic contact, around A.D. 1700 (Hay and Stevenson 1984:Tables 5–8). Discussed in greater detail below, a comparative perspective provided by the Hatch quarry and Houserville data may indicate that during the Early Woodland period there was an increase in the intensity of jasper acquisition at the quarry.

The Hatch Quarry Bald Eagle Jasper

The Hatch quarry was perhaps the most heavily exploited source of Bald Eagle jasper in the Nittany Valley region. Jasper is an isotropic microcrystalline silicate ($SiO2$) containing as much as 15–20 percent iron (Frondell 1962; Stevenson et al. 1990:46). Bald Eagle jasper contains a goethite ($FeO[OH]$) iron component, giving it a brown to yellow color (Miller 1982:7). Many jasper sources in Eastern North America, including the Hatch quarry, are found in Upper Cambrian and Ordovician carbonate formations of the Ridge and Valley physiographic province (Hatch and Miller 1985; Miller 1982:9; Stevenson et al. 1990:43). Jasper at the Hatch quarry originated around 500 million years ago and occurs in a deposit of Lower Ordovician dolomite known as the Nittany Formation (Clark 1965). Nittany dolomite is fine- to coarse-grained and contains chert nodules, oolitic chert, thin deposits of limestone, and sandy beds. The jasper was metamorphically derived from the reaction of a hot siliceous-laden liquid with this host dolomite formation (Stevenson et al. 1990:44). The hot liquid from deep in the earth's crust came to the surface via a fault trace that cuts across the Nittany Valley. The composition of the Nittany

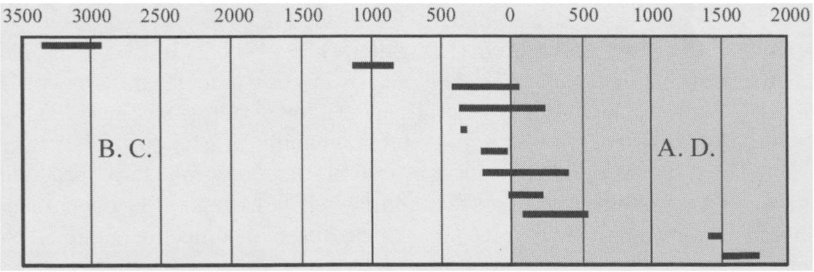

Figure 3. Temporal affiliation of the 11 radiocarbon dates retrieved from the Hatch quarry. (The bars bracket dates within two standard deviations.)

formation suggests that the goethite in Bald Eagle jasper came from the dolomite and limestone host material.[2]

At the Hatch quarry, Bald Eagle jasper consisted of nodular and tabular float material rarely larger than 20 cm in maximum dimension. Although the nodules and tablets occurred in roughly equal proportions, this characterization actually represents a continuum of raw material form. Overall, Bald Eagle jasper was not optimal for stone tool production, and was challenging to analyze for two reasons. First, its quality ranged from fine-grained homogenous to coarse-grained material, replete with inclusions and natural fracture planes (Hay 1980:73; Miller 1982:8). We estimate that at least 75 percent of the jasper on the surface was unsuitable for knapping.[3] Second, much of this surface jasper was thermally damaged, as evidenced by a high percentage of "potlids" and spalls resulting from frost fracture or surface fires. These items were not by-products of culturally induced heat treatment, but could be mistakenly classified as artifactual.

This observation raises the archaeological problem of distinguishing artifacts from geofacts (Barnes 1939; Bleed 1977; Duvall and Venner 1979; Grayson 1986; Luedtke 1986; Schnurrenberger and Bryan 1985; Warren 1914). Frost fracture can affect microcrystalline silicates in temperate regions where freezing temperatures result in the formation of angular or blocky fragments, scaling or exfoliation of cortical surfaces, and frost-pits (Lautridou et al. 1986:273; Luedtke1992:100; Sieveking and Clayton 1986). The latter are convex depressions left by frost-induced potlids. Similar to the results of improper heat treatment (Ahler 1983:5; Crabtree and Butler 1964), frost fracture reflects the damage that extreme and relatively rapid changes in temperature have on microcrystalline silicates. Such changes create stresses associated with thermal contraction, a consequence of the difference between the exterior and interior temperatures of a piece of stone. These conditions are likely to produce scaling and frost-pitting (Luedtke 1992:101; Sieveking and Clayton 1986:284).

The impact of frost fracture on microcrystalline silicates varies (Lautridou et al. 1986:270; Luedtke 1992:101; Sieveking and Clayton 1986:283). Besides thermal contraction, porosity and moisture content are also important variables. Siliceous stone most susceptible to frost fracture is highly porous or has relatively large pores, or both (Lautridou et al. 1986:271–277). For many microcrystalline silicates, these characteristics are associated with cortical regions. Interiors, in contrast, generally have a lower porosity (Lautridou et al. 1986:271). Frost fracture, therefore, predominantly affects cortical surfaces, where high porosity allows for absorption of more moisture, producing microcracks, spalling, and frost-potlidding when frozen. This phenomenon should be prevalent on porous microcrystallines in temperate regions with relatively high levels of precipitation.

Natural or culturally-induced burning of the quarry may also have damaged some of its jasper. Luedtke (1992:97) suggested that forest and brush fires are a significant source of unintentional heat damage. Lightning-induced fires certainly burned all over the Northeastern woodlands throughout prehistory (Little 1974:227). In addition, numerous Eastern North American ethnohistoric sources indicate widespread intentional burning for the purposes of land management (Little 1974:226; Martin 1973; Maxwell 1910; Russell 1983). Fires were set to increase productivity of local resources, and to clear land for swidden horticultural activities (Day 1953:334, 338; Lewis 1985:77). Microcrystalline lithic material on the surface can be drastically affected by such fires because they entail "rapid heat-up times, direct contact between chert and fire, and/or excessive ... temperatures" (Luedtke 1992:97). The exposure to this uncontrolled source of heat results in blocky angular flakes without bulbs of force, spalls, potlids, and crazing (Ahler 1983:4–5; Purdy 1974:41&52).

A significant number of jasper pieces were classified as non-cultural in the laboratory (*N* = 14,888, Table 1). Most of these pieces have attributes consistent with the effects of frost fracture and surface burning; some of them were initially mistaken for knapped fragments and flakes. Subsequent inspection, however, revealed that these "artifacts" lacked attributes such as platforms, positive or negative bulbs of force, or radial striations like those present on intentionally knapped material (Figure 4).[4] Many of them were also pale, chalky, and had a "soapy" feel, similar to the condition of frost-fractured stone (Sieveking and Clayton 1986:283).

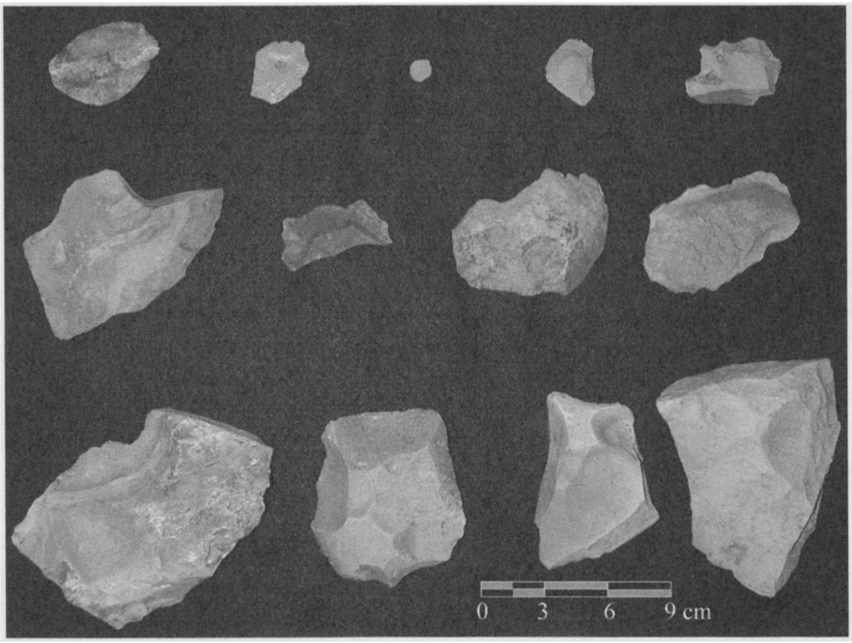

Figure 4. Thermally damaged geofacts.

We have three reasons for suspecting that frost fracture, rather than surface burning, was responsible for the majority of "damaged" non-cultural material. First, it has been documented that yellow to brown jasper usually turns red when it is subjected to heat (Shindler et al. 1982; however, see discussion below). Most of the non-cultural items were yellow (72 percent, n = 10,727). We would expect a greater percentage of these items to be red if they had been primarily produced by surface fires. Second, the variation in grain size and inclusions present in Bald Eagle jasper make it relatively porous. Moreover, the layering of coarser and finer-grained material results in the fragmentation of jasper into predominantly flat tabular pieces, many of which have frost-pitting attributes like those reported elsewhere (Luedtke 1992:101; Lautridou et al. 1986:fig. 32.2). Third, the temperate climate of Central Pennsylvania has 102 cm of annual precipitation and winters with multiple freeze–thaw cycles, conditions that are associated with the frost fracture of microcrystalline silicates (Lautridou et al. 1986:270).

Regardless of the origin of this damaged material, frost fracture and surface burning can produce "flakes" and "flaked material" that are not related to flint knapping. An awareness of these factors when working with surface samples in temperate regions is essential for correctly distinguishing artifacts from geofacts. Separating the artifacts preceded our flake classification, allowing us to accurately reconstruct the Hatch quarry reduction sequence outlined below.

Artifact Analysis

Advances in flaked stone debitage studies over the last 30 years have resulted in numerous techniques of analysis (Ahler 1989; Andrefsky 1998; Cowan 1999; Johnson 1987; Magne 1989, 2001; Parry 1987; Parry and Kelly 1987; Sullivan and Rosen 1985; Stahle and Dunn 1982). Although approaches vary widely in emphasis, there is no single best method applicable to every debitage assemblage (Andrefsky 2001:8; Magne 2001:22). To classify the Hatch quarry and Houserville artifacts, we used a method developed by Jeffrey Flenniken (Flenniken 1987, 1993a, 1996a, 1996b, 2003a, 2003b; Flenniken et al. 2001; Pecora 1990; Yerkes and Kardulias 1993:94–97). His approach classifies flaked stone artifacts and debitage according to technologically diagnostic attributes that have been verified by rigorous experimental replication (cf. Flenniken 1978, 1981, 1984, 1989). Artifacts are organized into analytic units representing knapping stages in a reduction continuum.[5] This approach is technological and behavioral because the stage transitions represent shifts in the techniques and decisions of prehistoric knappers, and thereby provide an understanding of exactly how stone tools were made (Sheets 1975:372).

There were three reasons for using an attribute-based flake typology to analyze the collections. First, the general quality of the Hatch quarry Bald Eagle jasper was poor; once again, more than half of the jasper pieces recovered at the site were not artifacts (Table 1). Consequently, aggregate or

Table 1. Counts of Hatch Quarry Artifacts and Debitage.

Sample portion	*Yellow*	*Red*	*Total*
Stage Diagnostics	3,860	1,193	5,053
Formed Artifacts	178	17	195
Nondiagnostic	4,444	2,849	7,293
Non-cultural	10,727	4,161	14,888
Totals	19,209	8,220	27,429

mass analysis would have been inappropriate unless the artifacts were initially separated from the geofacts by examining each one. Second, time constraints were not an issue. Even though the Hatch quarry ($N = 27{,}429$) and Houserville ($N = 744$) collections are relatively large, a closely supervised team of analysts was easily able to process the material in ten months.[6] Third, individual flake analysis permitted the classification of small diagnostic flakes. This is important, because small flakes are often lumped into late stage categories despite experimental studies indicating that they are produced at every reduction stage (Andrefsky 2001:8; Magne 1989:16; Patterson 1982, 1990; Stahle and Dunn 1982).

Artifacts were initially separated from geofacts and then classified into technologically diagnostic debitage, formed artifacts, and nondiagnostic debitage. The technologically diagnostic debitage was separated into five stages: primary decortication flakes, secondary decortication flakes, early interior flakes, late interior flakes, and percussion biface thinning flakes.[7] Our study emphasized flakes because they permit a reconstruction of the entire reduction sequence. Stage affiliation was determined according to the presence or absence of specific attributes. Flakes were also separated according to color (yellow versus red) to support inferences about intentional heat treatment, detailed in the next section.

Formed artifacts were defined as anything altered by flake removal (e.g., tested material, unifaces, bifaces) or by activities related to lithic processing (e.g., hammerstones). These items are briefly described here but treated in greater detail elsewhere (Murtha et al. 2001). The nondiagnostic debitage consisted of flake fragments and debris. Flake fragments are defined as portions of flakes without platforms, whereas debris consists of miscellaneous chunks produced during reduction. Contrary to the views of some researchers (Sullivan and Rozen 1985; Sullivan 2001), we think these items provide limited technological information.[8]

The Hatch Quarry Collection

Stage-Diagnostic Artifacts. Surface collection and excavation at the Hatch quarry resulted in the recovery of 5,053 stage-diagnostic artifacts, 195 formed artifacts, and 7,293 pieces of nondiagnostic debitage (Table 1).[9] All of these artifacts consist of Bald Eagle jasper. Stage 1 primary decortication flakes constitute 7.2 percent (*n* = 365) of the diagnostic collection (Table 2; Figure 5). These flakes are defined as those with 100 percent dorsal cortex (Figure 6a). They have cortical (55 percent, *n* = 201), single-facet (44 percent, *n* = 159), and multi-facet (1 percent, *n* = 5) platforms; 81 percent (*n* = 295) are yellow, and 19 percent (*n* = 70) are red (Table 2).

Stage 2 secondary decortication flakes constitute 45 percent (*n* = 2,275) of the collection (Table 2; Figure 5). In contrast to their primary counterparts, secondary flakes are defined as those with cortex covering less than 100 percent of their dorsal surfaces (Figure 6b).[10] These flakes have single-facet (64 percent, *n* = 1,466), cortical (30 percent, *n* = 690), and multi-facet (5 percent, *n* = 119) platforms. Like the primary decortication flakes, 81 percent (*n* = 1,853) of them are yellow, and 19 percent (*n* = 422) are red (Table 2).

Interior flakes generally represent various mid-sequence reduction activities. They lack dorsal cortex and evidence of formal platform preparation such as grinding; platforms are relatively thick compared to Stage 5 flakes, and they show a wide range of exterior platform angles.[11] Stage 3 early interior flakes constitute 33 percent (*n* = 1,662) of the collection (Table 2; Figure 5). Their

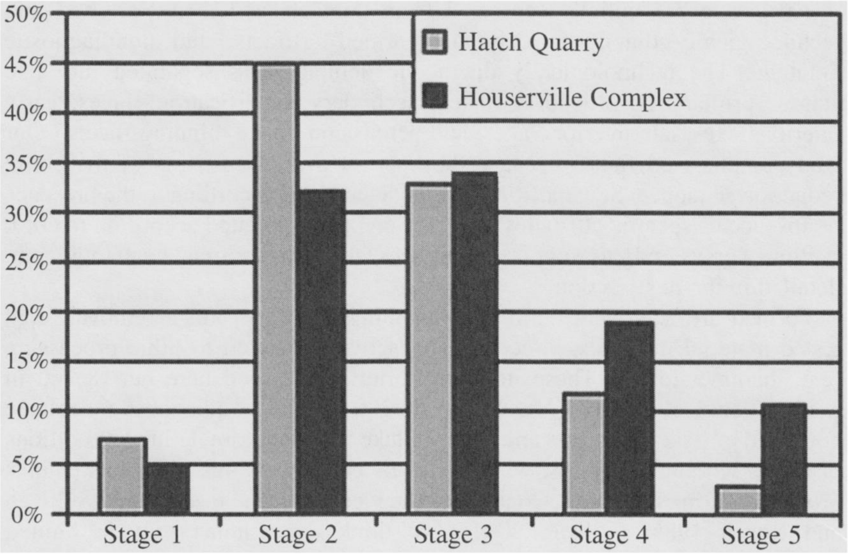

Figure 5. Percentages of stage-diagnostic flakes in the Hatch quarry and Houserville assemblages.

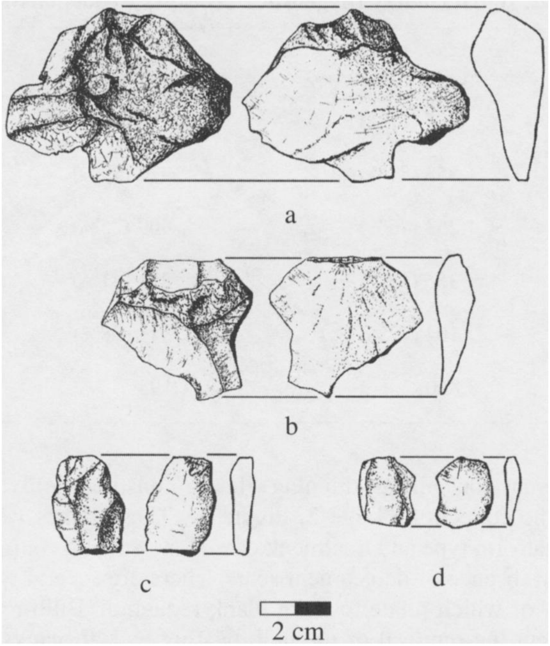

Figure 6. Technologically diagnostic flakes associated with Stages 1 through 4: a) Stage 1 primary decortication flake; b) Stage 2 secondary decortication flake; c) Stage 3 early interior flake; d) Stage 4 late interior flake (left view, dorsal surfaces; right view, ventral surfaces).

generally thick, triangular to rhomboidal cross-sections, and linear or irregular plan views (Figure 6c) indicate that they were used to remove prominent ridges and squared edges. Stage 3 reduction involved the detachment of undesirable jasper already exposed by decortication, the initial shaping of flake cores or bifaces, and the production of potential flake tools and blanks. Early interior flakes have single-facet (72 percent, *n* = 1,192), cortical (21 percent, *n* = 355) and multi-facet (7 percent, *n* = 115) platforms. Seventy-five percent (*n* = 1,253) are yellow, and 25 percent (*n* = 409) are red (Table 2).

Stage 4 late interior flakes constitute 12 percent (*n* = 606) of the collection (Table 2, Figure 5). Unlike their Stage 3 counterparts, late interior flakes have thin, straight to undulating rhomboidal cross-sections, and more regular or expanding plan views (wider at the distal than the proximal end) (Figure 6d). Many of them were removed as potential flake tools or blanks, or occasionally during the early thinning or "trimming" of large flake blanks. Late interior flakes have single-facet (81 percent, *n* = 491), cortical (11 percent, *n* = 64), and multi-facet (8 percent, *n* = 51) platforms. Fifty-nine percent (*n* = 355) are yellow, and 41 percent (*n* = 251) are red (Table 2).

Table 2. Hatch Quarry Diagnostic Flakes per Reduction Stage.

Stage	*Yellow Count (Percent/Stage)*	*Red Count (Percent/Stage)*	*Totals*
Stage 1	295 (81%)	70 (19%)	365
Stage 2	1,853 (81%)	422 (19%)	2,275
Stage 3	1,253 (75%)	409 (25%)	1,662
Stage 4	355 (59%)	251 (41%)	606
Stage 5	104 (72%)	41 (28%)	145
Totals	3,860	1,193	5,053

Stage 5 percussion biface thinning flakes constitute only 2.9 percent (*n* = 145) of the collection (Table 2; Figure 5). These flakes were classified according to platform type and treatment, cross/long-section configuration, and the presence or absence of detachment scars. There are several types of Stage 5 flakes, many of which relate to flake blank reduction. Bulb-removal flakes (*n* = 7) represent the removal of the bulb-bearing end of blanks (Figure 7a). Alternate flakes (*n* = 22) were used to reduce squared lateral edges of flake blanks by driving them down their margins. The platform of each successive alternate flake is the scar created by its previous counterpart, thereby requiring the knapper to flip the blank from face to face during the removal process.

Edge-preparation flakes (*n* = 67) were removed from the edge of a flake blank to impart curvature to its detachment scar (the flake's ventral surface). As a result, 61 of these artifacts have remnant detachment scars visible on their dorsal surfaces (Figure 7b). Imparting curvature to the detachment scar is important, because it permits the effective removal of subsequent biface thinning flakes. Half-moon-shaped margin-removal flakes (*n* = 21) are also detached from bifacial edges but they are the result of excessive force applied too far from the margin (Figure 7c). Two of these flakes have remnant detachment scars.

Formal biface thinning flakes are those with oval, expanding, or rounded plan views, flat to slightly bent long-sections, and lenticular cross-sections. Their platforms are often ground or abraded, indicating the careful platform preparation typical of systematic bifacial thinning; they are separated into early and late varieties (Figure 7d–e). Early percussion biface thinning flakes (*n* = 20) have dorsal scars running parallel to their long axes, indicating the previous removal of flakes from the same margin. One of these flakes exhibits a remnant detachment scar on its dorsal surface. In contrast, the late variant (*n* = 1) has greater long-section bend, a more pronounced lenticular cross-section, and one dorsal flake scar left by a flake that originated from the opposite biface margin (Figure 7e). The collection also has six thinning flakes and one notch flake that may have been removed with pressure techniques. If so, then their relatively low frequency suggests that pressure flaking was not commonly used at the quarry. These artifacts have been grouped with the Stage 5 material because it is uncertain whether they were removed by percussion or by pressure. Among the Stage 5 flakes, 72 percent (*n* = 104) are yellow and 28 percent (*n* = 41) are red (Table 2).

Formed Artifacts. Formed artifacts are a broadly defined category including items ranging from tested raw material to formal bifacial implements. The 195 formed artifacts from the Hatch quarry include 156 pieces of tested raw material, 4 core remnants, 5 flake blank fragments, 1 preform fragment, 3 unifacial artifacts, 4 flake tools, 19 bifaces, 1 hammerstone, and 2 battered artifacts.

Tested raw material consists of jasper tablets that were assayed for quality by removing at least one flake. In general, these artifacts have a poor-quality, silica-depleted composition, pre-existing checks or cracks, vugs (small unfilled cavities), and other obstructions inhibiting reduction. Consistent with the mean size of raw material at the quarry, they range from 10 to 20 cm in maximum dimension. The core remnants have haphazard flake scarring and lack formal shape (Figure 8a). One of them has a single platform; the others

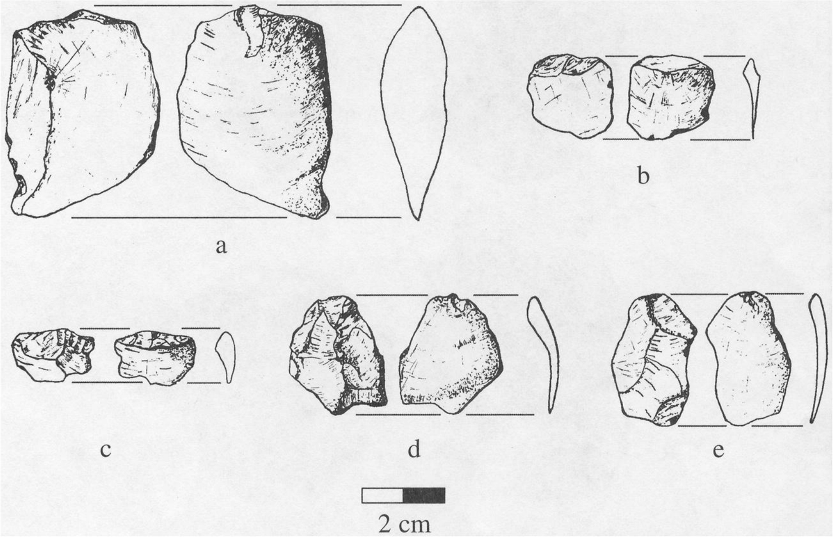

Figure 7. Technologically diagnostic flakes associated with Stage 5: a) bulb-removal flake; b) edge-preparation flake; c) margin-removal flake; d) early bifacial-thinning flake; e) late bifacial-thinning flake (left view, dorsal surfaces; right view, ventral surfaces).

have multiple platforms. These "cores" are pieces of relatively good jasper that were expediently utilized to produce flakes.

Flake blank fragments indicate that the production of blanks destined for further modification was one reduction strategy used at the site. These artifacts were identified on the basis of their detachment scars. All are the distal ends of blanks removed at the quarry prior to transporting the usable portion off-site. The preform fragment has several flakes removed from each of its faces. This artifact's ovular plan view and convex ventral surface indicate that it was made from a large frost potlid.

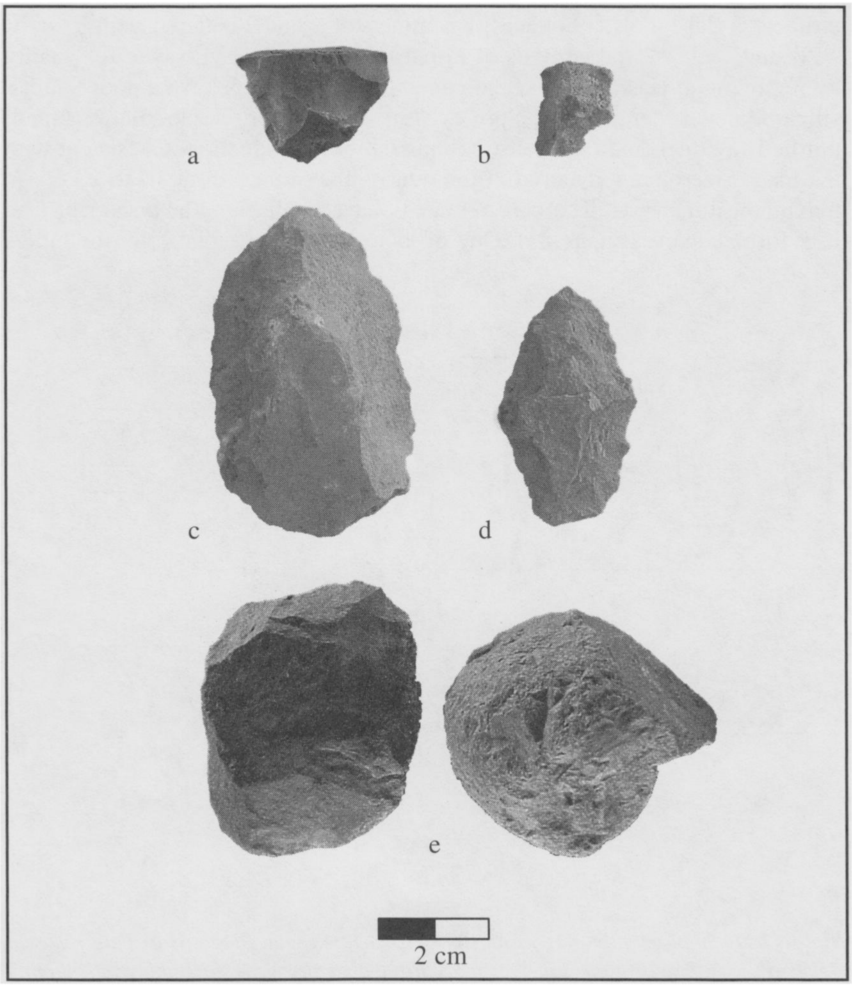

Figure 8. Formed artifacts recovered at the Hatch quarry: a) core remnant; b) flake tool; c and d) bifaces; e) battered implements.

Among the unifacial artifacts, two are complete and have a limited amount of edge damage, possibly related to use (although this is unclear because of the poor quality of the material).[12] Like the preform described above, the convex ventral surface of the uniface fragment indicates that it was made from a frost pot-lid. This artifact appears to have heavy use-wear and polish along one lateral margin. Flake tools in the collection show no significant modification except for limited use-wear and edge damage. Extant cortex on three of these tools indicates the expedient use of flakes at the quarry.

Besides tested raw material, bifaces are the most common formed artifacts at the quarry. Fourteen bifaces consist of jasper tablets with several percussion flakes removed from both faces (Figure 8c). These artifacts are made of poor-quality, silica-depleted material with extant cortical regions, and appear to be most consistent with Callahan's (1979:10) Stage 2 biface category. In contrast, five artifacts exhibit a greater degree of systematic flaking and are most consistent with Callahan's (1979) Stage 3 biface category (Figure 8d). Once again, the poor quality of the material makes it difficult to identify clear evidence of use-wear on any of these implements.

Three of the formed artifacts are tools used in lithic processing. The most notable is a small hammerstone (5.9 cm long) made of a sandstone river cobble with percussion battering at both ends. The size of the hammerstone indicates that it was only effective for removing relatively small flakes. The other processing artifacts are cobbles of jasper which we refer to as battered implements (Figure 8e). They lack formal shape and show localized regions of battering; these items may have been used to sharpen ground stone slabs, or as expedient hammerstones.[13]

The Houserville Collection

Stage-Diagnostic Artifacts. The Bald Eagle jasper artifacts from the Houserville complex include 258 stage-diagnostic flakes, 10 formed artifacts, and 476 pieces of nondiagnostic debitage (Table 3). The diagnostic flakes were sorted into the same five reduction stages as the Hatch quarry collection described above. Stage 1 primary decortication flakes constitute 4.7 percent (*n* = 12) of the collection (Table 4) and have cortical (*n* = 9) and single-facet platforms (*n* = 3). Half of them are yellow, and the rest are red. Stage 2 secondary decortication flakes constitute 31 percent (*n* = 81) of the collection and have single-facet (*n* = 55), cortical (*n* = 21), and multi-facet (*n* = 5) platforms. Thirty-seven percent (*n* = 30) are yellow, and 63 percent (*n* = 51) are red.

Stage 3 early interior flakes constitute 35 percent (*n* = 90) of the collection (Table 4) and have single-facet (*n* = 67), multi-facet (*n* = 13), and cortical (*n* = 10) platforms. Forty percent (*n* = 36) are yellow and 60 percent (*n* = 54) are red. Stage 4 late interior flakes constitute 17 percent (*n* = 45) of the collection and have single-facet (*n* = 38), multi-facet (*n* = 4), and cortical (*n* = 3) platforms. Twenty-two percent (*n* = 10) are yellow, and 78 percent (*n* = 35) are red.

Stage 5 percussion bifacial-thinning flakes constitute 12 percent ($n = 30$) of the collection. Represented in this stage are edge-preparation flakes ($n = 16$), one margin-removal flake, and early percussion bifacial-thinning flakes ($n = 3$). As was the case at the Hatch quarry, remnant detachment scars on seven of these artifacts indicate that the bifacial reduction of flake blanks was carried out at the Houserville complex. Twenty-three percent ($n = 7$) of the Stage 5 flakes are yellow, and 77 percent ($n = 23$) are red.

Formed Artifacts. The Houserville collection contains only 10 formed artifacts including two pieces of tested raw material, one preform fragment, three flake tools, and four bifaces. The two pieces of tested raw material are fragments with several flake scars. The preform fragment (Figure 9a) has a remnant detachment scar indicating that it was derived from a flake blank. The flake tools have possible polishing and edge-wear damage evident along one

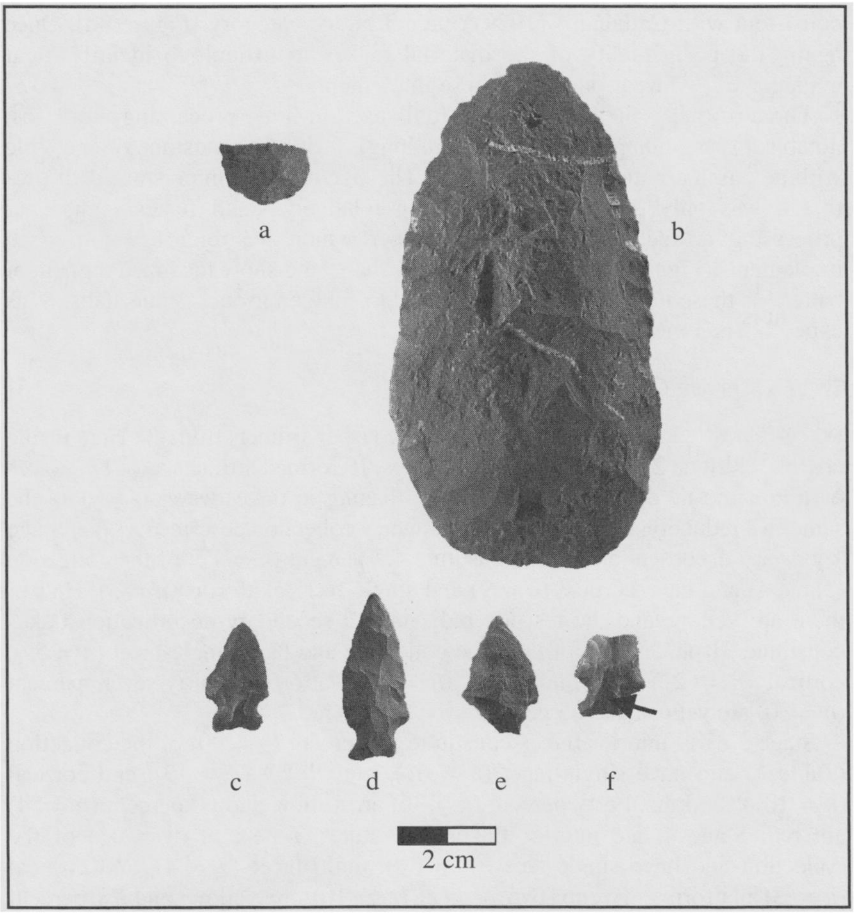

Figure 9. Formed artifacts recovered at the Houserville complex: a) preform fragment; b) biface; c–f) projectile points (note remnant detachment scar on f indicated by arrow).

Table 3. Counts of the Artifacts and Debitage from the Houserville Complex.

Sample portion	*Yellow*	*Red*	*Total*
Stage Diagnostics	89	169	258
Formed Artifacts	4	6	10
Nondiagnostic	113	363	476
Totals	206	538	744

lateral margin. One informal biface is made from a tablet with polishing and possible use-wear apparent along one distal lateral margin. These artifacts are all made of moderate- to poor-quality Bald Eagle jasper.

Three artifacts, made of relatively good-quality Bald Eagle jasper, represent what Callahan (1979) would refer to as Stage 3 or Stage 4 bifaces (Figure 9b). Their shape is much more refined than that of their counterparts at the quarry (Figure 8d). Each one clearly exhibits limited to moderate lateral-margin polishing and edge damage. A number of projectile points recovered from the Houserville area by private collectors were also analyzed during the project. These artifacts include Late Archaic Brewerton side-notched (Figure 9c, f) and Lamoka (Figure 9d) point styles. Described in greater detail in Murtha et al. (2001), some of them have remnant detachment scars, indicating that they were derived from flake blanks (Figure 9f).

Heat Treatment and Its Effects on Bald Eagle Jasper

During the classification of the Hatch quarry and Houserville artifacts, we also explored the nature of physical changes associated with heat treatment of Bald

Table 4. Houserville Complex Diagnostic Flakes per Reduction Stage.

Stage	*Yellow count (Percent/Stage)*	*Red count (Percent/Stage)*	*Totals*
Stage 1	6 (50%)	6 (50%)	12
Stage 2	30 (37%)	51 (63%)	81
Stage 3	36 (40%)	54 (60%)	90
Stage 4	10 (22%)	35 (78%)	45
Stage 5	7 (23%)	23 (77%)	30
Totals	89	169	258

Eagle jasper. This investigation was carried out to better interpret and therefore better understand the relationship between this technological application and the reduction sequence indicated by the debitage. An especially important goal was gaining a clearer understanding of how heat treatment relates to the yellow/red color of Bald Eagle jasper.

Systematic heat treatment of microcrystalline silicates was a widespread practice throughout prehistory (Crabtree and Butler 1964; Dunnell et al. 1994; Luedtke 1992; Mandeville and Flenniken 1974; Purdy 1974). The process enhances flakability by reducing fracture toughness, a measure of a stone's resistance to fracture propagation (Domanski et al. 1993; Flenniken and Garrison 1975; Griffiths et al. 1987; Kelterborn 2002; Skinner 1966). Effects of heat treatment are often associated with a change in color or luster. The extent of change, however, varies considerably, depending on the type of microcrystalline stone and on the heat treatment procedures used (Luedtke 1992:94).

Previous work at the Hatch quarry demonstrated that Bald Eagle jasper is naturally yellow in color (Munsell 7.5YR 5/6 – 10YR 5/8) because of its poorly crystallized goethite [FeO(OH)] iron component (Shindler et al. 1982:529). When the stone is heated, it undergoes a dehydration reaction whereby the goethite becomes a well-crystallized alpha hematite (Fe_2O_3). This dehydration reaction can begin at temperatures as low as 100° C. As temperature increases, Bald Eagle jasper can become progressively redder, often taking on a very dark color (Munsell 5R 3/4) at temperatures between 380° and 486° C (Shindler et al. 1982:528). Fracture toughness of Bald Eagle jasper can be reduced by as much as 50 percent after heat treatment (Shindler et al. 1982:532).

Shindler et al. (1982:530–535) suggested that the thickness of the red zone, or rind, would increase in proportion to the amount of time a stone was heated at temperatures exceeding 300° C (Shindler et al. 1982:530–535). According to this proposition, Hatch quarry and Houserville knappers heat-treated only those portions of the stone they intended to flake away. After removing the outer heat-treated layer, they would have had the option of repeating the process if they wanted to reduce the piece further.

We tested this conclusion and did not find a one-to-one relationship between the yellow-to-red color change and decreased fracture toughness. We gradually heated seven jasper samples in a Thermolyne pipe 10,500 furnace to temperatures of either 260° or 290° C, and then maintained these temperatures for at least eight hours before slowly allowing the samples to cool (Table 5). Some samples changed completely red, whereas others became red on the outside but remained yellow on the inside.

One could suggest that the yellow interiors of our heated samples did not reach high enough internal temperatures to change to red. This interpretation is unlikely. Experiments over the last forty years have shown that proper heat treatment involves the maintenance of an even temperature throughout a piece of stone (Ahler 1983; Crabtree and Butler 1964; Flenniken and Garrison 1975; Mandeville and Flenniken 1974). This is the principal reason why it must be heated and cooled gradually. If the process is done properly, then a stone's exterior temperature will never differ appreciably from its interior. Any significant variation in the exterior and interior temperature, brought about by rapid heating or cooling, will result in internal fracturing, crazing, spalling and potlidding; these traits are by-products of thermal shock (Ahler 1983:5; Crabtree and Butler 1964; Domanski et al. 1993:201; Luedtke 1992:97). Our samples did not display attributes associated with thermal shock, supporting the conclusion that their exterior and interior temperatures did not differ significantly.

One could also suggest that the yellow interiors of our heated samples did not undergo the structural benefits of heat treatment. Experimental flaking of our heated samples, however, indicated an appreciably higher degree of flakability, regardless of color change. Additionally, systematic microscopic observations were used to document structural changes related to heat treatment. The effects of this process can be identified by using scanning electron microscopy (Draper and Flenniken 1984; Flenniken and Garrison 1975; Johnson 1985). Pre- and post-heated flakes of our experimental samples were sputter-coated with gold in argon gas for one minute. They were then placed on standard scanning electron microscope (SEM) mounts and observed at 5,000x with a Hitachi S-3500N microscope. Flake surfaces were scanned to select an area appropriate for photographic documentation. This procedure is critical, given the generally poor quality of Bald Eagle jasper. Proper documentation requires the selection of a relatively "clean" portion of the better-quality jasper material, because coarse-grained areas and inclusion concentrations will not clearly show the effects of heat treatment.

Table 5. Munsell Color Readings for Samples of Jasper Before and After Experimental Heat Treatment.

Sample	*Temperature & Duration*	*Pre-Heat Treatment*	*Post-Heat Treatment, Red*	*Post-Heat Treatment, Yellow*
1	17 hours @ 260° C	7.5YR 5/6	10R 3/4	7.5YR 4/6
2	17 hours @ 260° C	7.5YR 5/6	10R 3/6	No Yellow
3	17 hours @ 260° C	10YR 5/8	10R 3/6	10YR 5/8
4	17 hours @ 260° C	10YR 5/8	10R 3/6	10YR 5/8
5	17 hours @ 290° C	10YR 4/4	10R 3/3 10R 4/6 7.5R 2.5/3	10YR 3/6
6	17 hours @ 260° C	10YR 4/6	10R 3/4	10YR 4/4
7	8 hours @ 290° C	10YR 5/6	10R 3/4	7.5YR 4/6

Micrographs of Sample 4 depict structural changes associated with heat treatment (Figure 10). The pre-heat treatment portion (Figure 10a) appears "grainy" and heterogeneous, whereas the post-heat treatment red (Figure 10b) and yellow (Figure 10c) portions are flatter and uniform, or "platy." The latter condition reflects the greater ease with which fractures propagate through heat-treated stone (Draper and Flenniken 1984).

Color change or not, our overall conclusion is that the interiors of our experimental samples reached the same general temperatures as their exteriors. Consequently, microcrystalline changes associated with heat treatment, specifically enhanced flakability, occurred on the interiors of our samples. It seems, therefore, that the reduction in fracture toughness resulting from heat treatment and the yellow-to-red color transition do not represent a one-to-one relationship. Accordingly, red Bald Eagle jasper is not an unequivocal indicator of heat treatment. Conversely, its yellow counterpart may not always indicate unheated jasper.

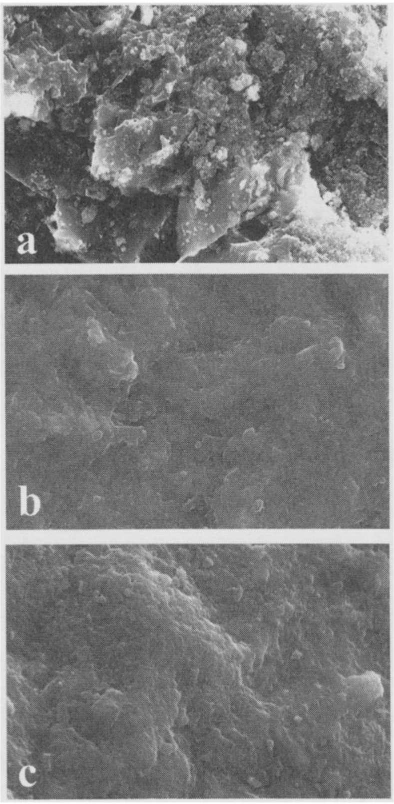

Figure 10. Pre- and post-heat treatment electron micrographs of Bald Eagle jasper: a) pre-heat treatment; b) post-heat treatment red; c) post-heat treatment yellow.

Our findings have two implications. First, the percentages of heat-treated artifacts estimated on the basis of jasper color might be slightly higher given that some yellow flakes could have been detached after heat treatment. Although most yellow flakes at the quarry were probably not systematically heated, the only way to be certain is to examine the stone microscopically. Second, Shindler et al. (1982:530) suggested that only the outer red surface of heat-treated stone incurred the benefits of the process. After removing the red region, therefore, one would heat-treat the stone again if further reduction was desired. Based on our findings, however, we suggest that multiple heat treatments were unnecessary. Our experiments confirmed that jasper heated at the proper temperature for the right amount of time will incur the structural benefits of the process regardless of color change.

The Reduction Sequence of Bald Eagle Jasper at the Hatch Quarry and Houserville Complex

Our classification of the Hatch quarry and Houserville artifacts, in addition to the information gained from heat treatment experimentation, allowed us to reconstruct the reduction sequence of Bald Eagle jasper that took place at these sites. Our work is in general agreement with that of Hay (Hay 1980; Hay and Stevenson 1984; Stevenson and Hay 1980), but the scale of our study permitted us to refine the earlier interpretations.

Once again, the Hatch quarry represents a *prospect site* (Wilke and Schroth 1989) where the prehistoric knappers came to obtain jasper nodules and tablets scattered across the surface. The majority of diagnostic debitage from the quarry indicates an emphasis on decortication and lithic processing up to the stage immediately preceding formal tool manufacture. Stage 1 and 2 decortication flakes comprise more than 52 percent of the diagnostic artifacts (Table 2). This high percentage of cortical flakes is characteristic of poor-quality sources yielding relatively small pieces of "float" material (e.g., prospect sites, Wilke and Shroth 1989). Jasper pieces at the Hatch quarry rarely exceeded 20 cm in maximum dimension, and most of their surfaces were covered with weathered cortex. Experiments have shown that the reduction of relatively small pieces of raw material covered with cortex will produce assemblages with high percentages of cortex-bearing flakes (Bradbury and Carr 1995). Numerous decortication flakes at the quarry reflect this tendency, indicating the testing and rejection of small to mid-sized nodules and tablets with a preponderance of weathered cortex. The high frequency of primary flakes with cortical platforms (55 percent, Table 2) is also consistent with these activities.

Stage 3 early interior flakes were used to remove poor-quality material during the initial shaping of flake cores and bifaces, or were detached as potential flake blanks destined for further modification. In contrast, Stage 4 late interior flakes generally represent the earliest phase of formal tool production. We suggest that heat treatment of most Bald Eagle jasper at the Hatch quarry took place between Stages 3 and 4. Although the proportion of red flakes generally increases throughout the sequence, the jump between Stages 3 (25 percent) and 4 (41 percent) (Figure 11) is highly significant (χ_2 $P < .005$, $df = 1$). We recognize that color is not a fail-safe criterion for identifying culturally heat-treated jasper, but we think that most yellow flakes were not subjected to this process.

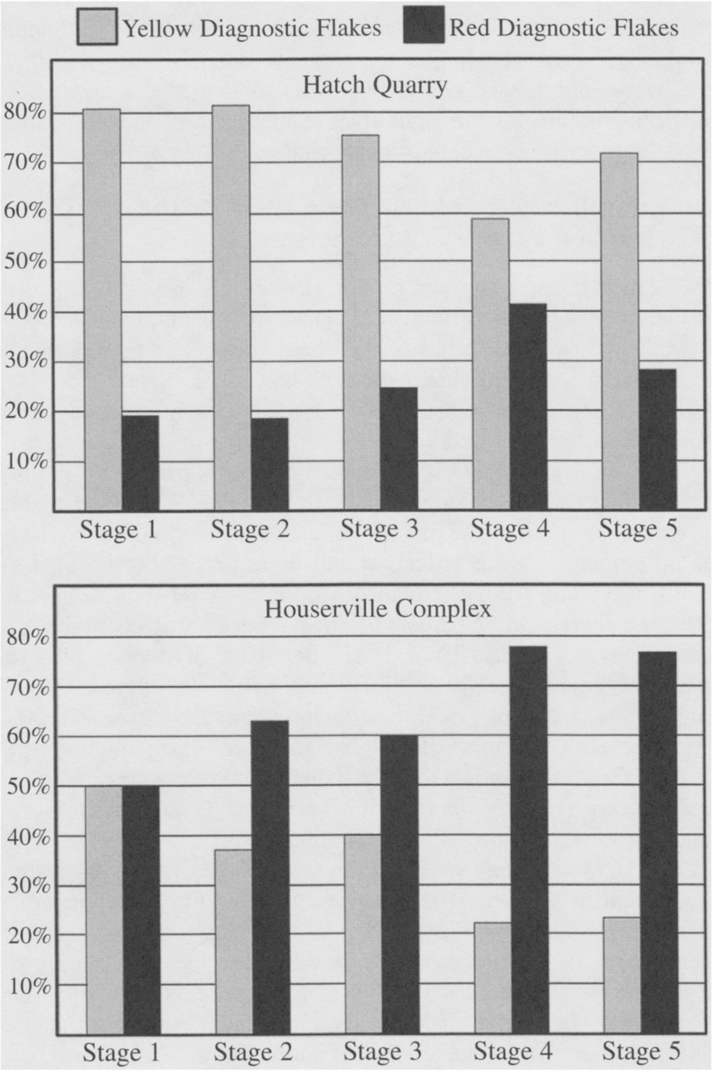

Figure 11. Stage distributions of technologically diagnostic flakes from the Hatch quarry and Houserville complex. (Bars represent the percentages of yellow and red flakes per diagnostic stage.)

Heat-treating between Stages 3 and 4 was probably a matter of efficiency. Following the removal of undesirable material, heat-treating efforts would have concentrated on stone intended for further use. In particular, heat treatment of flake blanks would have been most efficient because they are thinner and less susceptible to thermal shock (Luedtke 1992). Formal tool production associated with Stages 4 and 5 requires a greater degree of knapping control than is necessary earlier in the sequence. Hence, the enhanced flakability of heat-treated jasper would have facilitated this need.

Our data indicate that much of the jasper was carried away from the quarry as potential flake tools, flake blanks, and bifaces. The inference that flake blank production was an important strategy is supported by Stage 5 percussion bifacial-thinning artifacts found at the quarry. Although Stage 5 flakes are not well represented, many of them have remnant detachment scars indicative of flake blank reduction. Some formed artifacts also have remnant detachment scars. In general, bifaces from the quarry were not heavily processed. Most of them were informal implements with only a few flakes removed from both faces. These bifaces were probably left at the quarry because they were made of poor-quality jasper. They primarily indicate the testing of raw material for quality with little investment in subsequent on-site reduction. Few formal tools, and a complete lack of well-worn examples, suggest that the quarry-based retooling associated with some other source locations in northeastern North America (Gramly 1980) did not take place at the Hatch quarry.

We think that the nearby Houserville inhabitants obtained most of their tool stone from the Hatch quarry because more than 95 percent of their artifacts are made of Bald Eagle jasper. Compared with the quarry material, the stage-diagnostic debitage from the Houserville complex indicates activities which generally occur later in the reduction sequence. Even though this collection was sorted into the same five reduction stages, a χ_2 test indicates that despite disparate sample sizes, the differences in percentages per stage between the two sites (Figures 5 and 11) are highly significant ($P < .005$, $df = 4$). Evidently, some cortex-bearing jasper was taken to the Houserville complex. Cortex is present, however, on only 36 percent of the Houserville artifacts, as opposed to 52 percent at the quarry. This difference supports the inference that the majority of cortex was removed at the quarry before transporting the jasper to the Houserville complex.

One notable difference between the Hatch quarry and Houserville collections is the higher number of Houserville flakes attributed to Stages 4 and 5. This pattern holds true *despite the fact that the Houserville sample was collected without the use of screens*. Consequently, we believe that the difference between the collection strategies used at the Hatch quarry and Houserville complex works in favor of our argument; it is likely that later reduction stages associated with greater percentages of smaller flakes are under-represented at Houserville. The higher relative frequency of flakes attributed to late-stage reduction is exactly what would be expected if the production of useable flakes and formal tools took place primarily at the

Houserville complex. Cursory examination of Bald Eagle jasper flakes from the nearby Shuey site (36CE362) shows a similar pattern. This collection also has a greater percentage of late interior and percussion bifacial-thinning flakes than debitage from the Hatch quarry (Mary Alice Graetzer, personal communication 2001).

Another interesting aspect of the Houserville collection is the distribution of yellow and red flakes per reduction stage. Compared to the Hatch quarry, the percentages of red jasper flakes are higher for all stages (Figure 11). This is also consistent with the suggestion that formal tool production using heat-treated stone was undertaken predominantly at the Houserville complex. What is especially noteworthy, however, is the significant (χ_2 $P < .05$, $df = 1$) increase in the proportion of red to yellow flakes between Stages 3 to 4. This marked jump mirrors the pattern in the Hatch quarry distribution, although the percentage of red Houserville flakes is much greater. Consequently, we think that most heat treatment at both the Hatch quarry and the Houserville complex was applied between Stages 3 and 4. This pattern reflects technologically complementary reduction strategies, suggesting that knapping activities at the Hatch quarry and Houserville complex were behaviorally linked. The production and use of flake blanks, indicated by artifacts with remnant detachment scars, is also consistent with this inference.

Besides five possible pressure biface thinning flakes and one notch flake from the Hatch quarry, evidence of significant bifacial reduction by pressure was not identified. Since the excavated deposits were screened through 1/8-inch mesh, more pressure flakes would have been recovered if these activities had been performed at the site. In all probability, pressure flaking was primarily done at the Houserville complex, although flakes indicating such activities were missed because the Houserville sample was not collected with screens. Most of the Houserville projectile points, however, clearly exhibit pressure-flake scars.

We are able to make only tentative statements about diachronic technological change in the use of Hatch quarry jasper. Our test excavations, blade stripping of the site's surface, and backhoe trenches revealed no evidence of stratified deposits that would provide such information. This condition probably related to the scattered nature of the "float" jasper deposits and the intensive modern use of the quarry area for agriculture and pasturage. Nevertheless, the comparative perspective provided by the Hatch quarry and Houserville data offers a basis for inferring technological change. Since most of the Hatch quarry radiocarbon dates come from probable heat-treatment features (Murtha et al. 2001), and 73 percent of these features ($n = 8$) date between 1100 B.C. and A.D. 500 (Figure 3), we suggest that heat treatment might have become a prevalent component of the reduction sequence during the Early Woodland period (1100–100 B.C.). It also might indicate more intensive use of the Hatch quarry at this time despite the moderate to poor quality of its tool stone. A greater demand for Bald Eagle jasper would have made heat treatment an attractive innovation because it makes the stone easier to work with. It is noteworthy that the timing of this hypothesized intensification coincides with a region-wide rise in population that occurred sometime around the Archaic to Woodland transition (Adovasio et al. 2001).

Our hypothesis contrasts with the earlier suggestion that the most intensive use of the Hatch quarry took place during the Early to Middle Archaic (Hay 1980; Hatch and Miller 1986:17). This proposal was primarily based on projectile points recovered at the Houserville complex. Consequently, we suggest that the temporal affiliation of the Houserville projectile points (Hay and Hatch 1980; Hay and Stevenson 1984) may have to be reassessed or refined. It is possible that some point styles primarily ascribed to the Archaic might have persisted into Woodland times, or date more appropriately to the Archaic/Woodland transition. Without a doubt, recent research elsewhere in the mid-Atlantic region has resulted in the recovery of supposed Archaic points in Early Woodland contexts (Hummer 1991; Kraft 1989; Payne 1990; Stewart 1986, 1995:181). At the very least, these findings indicate greater intra-regional variation in the temporal affiliation of some mid-Atlantic point styles than was previously thought. Resolving the degree to which this was the case at the Houserville locality will require more systematic excavations. One essential objective would be the recovery of securely dated stratigraphic collections of debitage and projectile points.

Conclusions

Archaeological studies of prehistoric quarries can benefit from the technological analysis of all available artifacts, not just formal tools (Purdy 1984:119). Data presented here demonstrate the valuable information that flakes can reveal about prehistoric technological behavior. This evidence was gathered using a technological analysis of flake attributes that permitted the reconstruction of activities involved in the acquisition and production of stone tools at the Hatch quarry and the Houserville habitation complex.

Our analysis indicated that much of the Bald Eagle jasper at the Hatch quarry was affected by frost fracture and by naturally or culturally induced surface burning. Careful attention to attributes, such as the presence of striking platforms and bulbs of force, was essential for accurately identifying the real flaked-stone artifacts. In addition, the attribute-based typology (Flenniken 1981, 1993a, 2003a, 2003b) that we used allowed us to separate the diagnostic debitage from the Hatch quarry and Houserville complex into five technologically complementary reduction stages. Accordingly, the data indicate an emphasis on decortication and early-stage processing at the quarry, and latter-stage activities at the Houserville complex. This finding supports the interpretation that the Houserville inhabitants acquired and initially processed jasper at the Hatch quarry, and then carried it back to their homes where tools were finished. This relatively simple procurement strategy represents a sequential system of direct access (Ericson 1984:4).

We also established that although red flakes do reflect heat treatment, stone subjected to this process can retain the yellow color of unheated Bald Eagle jasper. This might appear to undermine the reliability of any conclusions about heat treatment based on flake color. The feasibility of archaeological interpretations is supported, however, by data that reflect a clear pattern (Amick et al. 1989:9; Luedtke 1984:97). Such patterning is likely to be the result of human behavior. We have concluded that most heat treatment was applied during the middle portion of the sequence. This assertion is based on a clear pattern showing a significant jump in the frequency of red flakes from Stages 3 to 4; this jump is apparent at both the Hatch quarry and the Houserville complex. Such a practice made good economic sense because it enhanced the flakability of stone intended for further modification.

Undoubtedly, some yellow flakes may have been heated, but most of them probably were not. We know that heat-treating Bald Eagle jasper results in reddening, at least on the surface of the stone. Red coloration, therefore, is an acceptable basis for inferring heat treatment *when considering a population of artifacts*. Moreover, it is no coincidence that the frequency of red flakes increases after Stage 3, when the benefits of the process would have been optimal. Once again, it is the patterning that is significant.

In conclusion, this research demonstrates that a stage-based technological analysis is a valuable methodology for wading through the considerable amount of debitage associated with quarries. We now know more than the simple fact that prehistoric knappers obtained tool stone at the Hatch quarry. Our reconstruction of the production steps reflects the decisions, activities, and considerations involved in raw-material selection, primary processing, heat treatment, and final tool manufacture. Moreover, the majority of radiocarbon dates obtained from probable heat-treatment features suggests that this technological application became most prevalent sometime after 1000 B.C. (Figure 3). The Hatch quarry was certainly used during the Archaic, but the most intensive exploitation of this inferior source of tool stone might have coincided with the increase in population during the Early Woodland period.

Our study has provided a dynamic and comprehensive view of the sequential nature of ancient stone-tool production at the Hatch quarry and Houserville complex in Central Pennsylvania. As such, it is both holistic and comparative, and therefore, represents an approach true to the goals of anthropological archaeology. We think James Hatch would have been pleased with our findings. We only regret that he is unable to share in the satisfaction of a successful project that he made possible.

Acknowledgments

First and foremost, we would like express our appreciation to the late James Hatch, for whom the site has been named. It was his ongoing interest and concern for this site that made our research possible. Moreover, we appreciate the work of Conran Hay and the numerous individuals who were involved in earlier research efforts at the Hatch quarry and Houserville complex. In addition, the generous assistance and comments from Jeffrey Flenniken during the analysis and write-up were invaluable. We also thank Martin Magne, Kenneth Hirth, and four anonymous reviewers for their comments and suggestions on earlier versions of the manuscript. In addition, we are indebted to the students who participated in the project, including Steven Barry, Jennifer Clarke, Judy Cooper, Adam Freeburg, Neal Murray, Andy Olsen, and Gary Stenchcomb. We also must acknowledge the unwavering support of Dean Snow throughout the entire project, and the various forms of assistance provided by Mary Alice Graetzer, Anna Backer, Greg Bondar, Kurt Carr, Melissa Diamanti, Rand Greubel, Francis Hayashida, Uwe Nerger, Michael Stewart, Noel Stratten, Alan Reed and Peter van Rossum.

Notes

1. The Hatch quarry was formerly called the Tudek Site after the Pennsylvania State University student, Bob Tudek, who brought attention to the site in 1978. It has also been referred to as the Houserville quarry site (Hay and Stevenson 1984). During our project, we renamed it the Hatch quarry in memory of the late Pennsylvania State University archaeology professor James Hatch who made this project possible at a time when his health was declining. James Hatch dedicated much of his career to studying the prehistory of Pennsylvania and he is sorely missed.

2. Nittany dolomite and limestone in the Centre County region of Pennsylvania were extensively mined for their high iron content during the 19th century (Stevenson et al. 1990:46).

3. Fully 54 percent of the jasper recovered in the surface collections was identified as non-cultural in the laboratory (Table 1; 14,888/27,429 = 0.543). Considering that obvious non-artifactual pieces of jasper were not collected, and the overall moderate to poor quality of the flakes, we estimate that only about 25 percent of the surface jasper is viably flakable. This was probably also the case prehistorically. It is unlikely that the quarry has been used as a serious source of tool stone for at least 250 years (Figure 3). This length of time, the fact that the site has been repeatedly plowed over the last one hundred years, and the lack of evidence for more substantial subsurface deposits of jasper, suggests that the tool stone on the modern surface accurately reflects the general quality of this source.

4. Although the Hatch quarry jasper is inferior material, knapping attributes were identifiable. This was true even for poor-quality material experimentally knapped by Andrews. Consequently, we are confident that the majority of artifacts were correctly separated from the non-cultural stone.

5. Strictly speaking, we recognize that knapping does not proceed in stages. Staging is an analytical technique for organizing continuous data into ordered units (Collins 1975; Sheets 1975; Stahle and Dunn 1982). Knapping is essentially continuum mechanics: you cannot skip a step in the process, so in fact every flake represents a stage (Flenniken 1984). Stages are not real but flake tool producing behavior is (or rather, was) and the debitage reflects the behaviorally based sequential reduction of raw material into usable implements. Furthermore, we do not maintain that every flake was correctly identified in our analysis. Individual flakes have limited utility because any technological sequence will produce a minority of flakes that are not characteristic of the part of a continuum when they were removed, or flakes that are diagnostic of other reduction strategies altogether (Flenniken, personal communication 2004; Magne 1985). Instead, our approach is founded on reconstructing reduction behavior by looking at artifact populations. The assumption is that most flakes will be identified correctly thus yielding a technological pattern. Patterns in archaeological data reflect patterned cultural behavior; using probabilistic approaches, the identification and interpretation of this patterned behavior is a primary goal of scientific archaeology (Ensor and Roemer 1989:177; Magne 2001:29).

6. The analysis was conducted by Andrews and six undergraduate students. Initially, each student was given a knapping demonstration to see how the flake types were derived and what attributes to look for. This was done first with obsidian and then with poor-quality Hatch quarry jasper, exposing the students to a range of attribute clarity. Each analyst initially examined two or three collection bags (depending on their size) with Andrews, and were then permitted to analyze on their own. Upon completion of each bag, the results were checked by Andrews. The frequency of bag checks declined as student competence with the system increased. Once again, we do not claim that every flake was correctly identified, or that each analyst would assign a given flake to the same stage. We are confident, however, that the general pattern of reduction activities reflected by both assemblages was accurately defined.

7. We maintain that the use of primary and secondary flake types as defined by this study is useful for analyzing the Hatch quarry and Houserville debitage collections. This is especially true for the Hatch quarry because it represents the initial end of the reduction sequence where these artifact categories have proven to be analytically useful (Amick et al. 1989; Magne 1985, 1989; Odell 1989). They also provide information on how the quality and form of Bald Eagle jasper affected the reduction and consumption of this material.

8. Some researchers have suggested that high frequencies of flake fragments reflect bipolar reduction (Morrow 1997:54; Sullivan and Rozen 1985). We agree with this observation but these items are also produced by all flaked-stone tool technologies. Artifacts diagnostic of bipolar technology, such as wedge-shaped flakes with stress lines and crushing at both ends (Magne 1989:18), were not

identified in the Hatch quarry and Houserville collections. Therefore, we think these techniques were not important for reducing Bald Eagle jasper.

9. Some readers may object to the accuracy of our analysis on the grounds that the diagnostic sample only represents 42 percent of the total sample of artifacts (for the figures consult Table 1). Andrews, however, has worked with several sizable collections where only 1/3 to 1/2 of the flakes are diagnostically identifiable (Andrews 2002a and b). Jeff Flenniken, who has analyzed well over three thousand collections, suggests that the Hatch quarry sample has a comparatively high percentage of diagnostic debitage (Flenniken, personal communication 2004).

10. Stage assignments can be problematic for flakes with attributes indicative of more than one stage. For example, a flake with some dorsal cortex could have a greater number of attributes consistent with bifacial thinning. In such a case, this flake would not be classified as Stage 2 secondary decortication; it would be classified as a bifacial-thinning flake. In our analysis stage assignments were based on the overall composition of a flake's attributes.

11. Exterior platform angle is defined as the angle created by the platform and the dorsal surface of a flake (Dibble and Whittaker 1981; Pelcin 1997). At the Hatch quarry many interior flakes were used in the initial shaping of nodules and tablets into bifacial cores or bifaces; a considerable number of these flakes had exterior platforms of roughly 50–60 degrees.

12. A wide-field geological microscope with objectives of 10x, 15x, and 20x was used to examine the edges of artifacts for evidence of use-wear. This was not a primary objective of this phase of analysis so all determinations are preliminary.

13. The battered implements show rounded battering surfaces (Figure 8e) most consistent with the type of wear produced by pecking ground stone slabs for effective use (Flenniken 1993b). This begs the question of why they were found at the quarry, especially considering that there were no ground-stone artifacts collected during the project? It is possible that evidence of ground stone has been removed from the quarry by private collectors who have scoured the site over the last fifty years. Alternatively, if the cobbles were not used to "sharpen" ground stone, they may have been used as expedient knapping implements.

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