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The Analysis of Stone Tool Procurement, Production, and Maintenance

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Abstract Researchers who analyze stone tools and their production debris have made significant progress in understanding the relationship between stone tools and human organizational strategies. Stone tools are understood to be morphologically dynamic throughout their use-lives; the ever-changing morphology of stone tools is intimately associated with the needs of tool users. It also has become apparent to researchers that interpretations of lithic analysis are more productive when the unique contexts and situations for which lithic artifacts were made, used, modified, and ultimately discarded are considered. This article reviews the recent literature on stone tool production with an emphasis on raw material procurement, manufacturing techniques, and tool maintenance processes as they relate to adaptive strategies of toolmakers and users.

Keywords Lithic technology · Artifact curation · Reduction sequences · Artifact life history

Introduction

Because lithic artifacts do not degrade easily, they are arguably the most abundant artifact type found on ancient archaeological sites in most parts of the world. In many places lithic artifacts represent the only artifacts that have survived decomposition, and in this regard they provide the only evidence about past human activities, actions, and associations. For this reason alone, lithic artifacts might be considered the most important artifact category for understanding the oldest of human behaviors. It is little wonder that the number of volumes on lithic analysis has multiplied rapidly over the past decade or so (Andrefsky 2001a, 2005, 2008a; Clarkson and Lamb 2006; Elston and Kuhn 2002; Holdaway and Stern 2004;

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Kardulias and Yerkes 2003; Kooyman 2000; McPherron 2007; Odell 2004; Pitblado 2003; Roux and Bril 2005; Soressi and Dibble 2003). The growth in lithic analytical methods within this time has been diverse, with multiple unique applications and techniques that do not always appear to be interchangeable or even complementary.

This study reviews that body of recent lithic analytical investigations associated with stone tools and debitage. Central to this review is an attempt to integrate the various analytical approaches into a larger framework for understanding the contexts of lithic artifact procurement, production, maintenance, and discard. These dimensions of stone tool variability are often subsumed under the concept of lithic technological organization (Binford 1973, 1977; Kelly 1988; Shott 1986). Lithic technological organization refers to the manner in which human toolmakers and users organize their lives and activities with regard to lithic technology. Since foraging societies are most often associated with lithic technology, most studies of lithic technological organization deal with forager adaptive strategies. In this context, the manner in which lithic tools and debitage are designed, produced, recycled, and discarded is intimately linked to forager land-use practices, which in turn are often associated with environmental and resource exploitation strategies (Andrefsky 2006; Carr 1994; Koldehoff 1987; Nelson 1991; Torrence 1983). The recent literature in this area is extensive and complex. It deals not only with aspects of stone tool production but also human land use and modeling strategies, artifact functional studies, and even paleoenvironmental reconstruction (Brantingham and Kuhn 2001; Hardy et al. 2001; Jeske 1989; McCall 2007; Riel-Salvatore and Barton 2004). For this reason I have elected to narrow my review to studies that intersect with lithic technological organization, primarily in the areas of artifact procurement, production, reduction, maintenance, and discard.

Before discussing these concepts I clarify the way that I use three terms that are sometimes used interchangeably, sometimes with distinctive meanings. I use the term “production” to talk about the manufacture of “tools” using pressure or percussion flaking methods. I use the term “reduction” to talk about the removal of detached pieces from cores. So “reduction” refers to the process of flake removal for the acquisition of detached pieces and “production” refers to the process of flake removal for the purpose of making, shaping, or resharpening a tool: I talk about core “reduction” and tool “production.” I use the term “retouch” as a generic descriptor for removing detached pieces from an objective piece (Andrefsky 2005, p. 12). Essentially, retouch is the process by which flintknappers produce tools and reduce cores. With this definition, retouch can be used to describe the intentional modification of a tool or flake blank edge by the removal of chips. A tool can be retouched to prepare its edge for such activities as cutting, scraping, or sawing. In all cases the objective piece gets progressively smaller as retouch occurs; for that reason many use the term “reduction” to refer to both core and tool retouching.

Artifact life history and operational chains

Lithic tools often undergo a series of transformations from the time they are produced or drafted into service until the time they are ultimately discarded. Such transformations relate to all manner of social and economic situations of the tool users. Tools are sharpened when they become dull. They are reconfigured or discarded when they are broken. They are modified to suit a certain task in a certain context. Their uses are often anticipated, and they are produced in anticipation of those uses. These and countless other examples of tool transformations can be characterized as part of the life histories of lithic tools. Lithic tools are dynamic in their morphological configurations because of these life history transformations. A flake blank originally used as a meat-slicing knife with an acute edge angle may be transformed due to dulling and edge resharpening into a tool that contains a serrated edge used for sawing. This tool can be intentionally chipped and shaped into a projectile point and mounted into a shaft for use as a dart. A single specimen can undergo numerous transformations during its life history. Such life history transformations not only change the tool form but also may change the tool function; both formal and functional changes are often associated with human land-use practices. Stone tool life histories may also be less deliberate. The morphological transformation of stone tools may come about through the gradual use and resharpening of the tool without a conscious effort on the part of the tool user to alter the shape of the specimen (Andrefsky 1997, 2007b; Hiscock and Attenbrow 2003; Hiscock and Clarkson 2005; Tomaskova 2005).

The life history of stone tools and cores is often associated with the retouch of these objective pieces (see Andrefsky 2005 for definitions and discussion of the term objective piece). Since stone tools and cores are produced by retouch or the removal of stone from a nucleus or objective piece, it is easy to equate stone tool life histories with the unidirectional retouch of stone—the more an objective piece is retouched the further along the specimen is in its life history. Some of the early thinking in this area can be attributed to Holmes (1894), who coined the phrase “lithic reduction sequences.” Lithic reduction sequences have traditionally been associated with core tool reduction phases, stages, or continua (Magne 1985; Pecora 2001; Shott 1993; Van Peer 1992; Wurz 2002). This is also true of North American bifacial technology, where the trajectory of retouch begins with raw material acquisition and ends with notching, fluting, or final sharpening of the tip and edges (Callahan 1979; Johnson 1989; Whittaker 1994).

The concept of reduction sequences of chipped stone tools deals with the transformation of tools during their procurement (Callahan 1979), production (Bradley 1975), use (Goodyear 1974), and maintenance (Collins 1975). Reduction sequences, however, do not deal only with the stages of a tool’s life history; they include the broader arena of archaeological contexts such as the properties of raw materials used to make tools (Ashton and White 2003; Bradbury and Franklin 2000; Pecora 2001) and the intended tasks or activities for which tools were used (Sassaman 1994; Tomka 2001; Villa and Soressi 2000). The concept of reduction sequence analysis is not fixed into preconceived stages or steps. Reduction sequence analysis is integrated into the contexts from which tools are produced, procured, and used. These may be variable depending on the situation at hand with which the toolmaker must deal.

Lithic researchers today cannot discuss the notion of lithic reduction sequences without some reference to the concept of *chaîne opératoire*. Since Leroi-Gourhan’s

(1964) introduction of this term, it has since been adopted by archaeologists working in most parts of the world (Audouze 1999; Boeda 1995; Geneste 1991; Grimaldi 1998; Schlanger 1994; Sellet 1993; Simek 1994; Tostevin 2007). Advocates of the chaîne opératoire concept claim that it "comprises a much wider range of processes than do the English terms reduction sequences or even lithic tool production" (Simek 1994, p. 119). Inizan and colleagues suggest that chaîne opératoire includes the processes from the procurement of raw materials, through its stages of manufacture, use, and including its discard (Inizan et al. 1992; Sellet 1993). Other archaeologists challenge the notion that chaîne opératoire is more encompassing than the concept of "reduction sequences." For instance, Shott (2003, p. 103) suggests that some archaeologists have adopted the term chaîne opératoire as "…tactical rather than analytical, a way to register intellectual pedigree rather than operational method. There is nothing in their use of chaîne opératoire that could not be accomplished as easily and plainly with reduction sequence."

Perhaps the greatest difference between the concepts of chaîne opératoire and reduction sequence analysis is the embedded notion that chaîne opératoire in some way captures the cognitive intents of toolmakers and users. In many regards the original practitioners of the chaîne opératoire concept recognize culturally distinct tool production, use, maintenance, and discard patterns (Boeda 1995). Different chaînes represent different cultures (Audouze 1999; Boeda 1995). In this regard operational chaînes not only describe the mechanical processes of tool production but also reveal the cultural system responsible for the production process.

In my opinion this premise is flawed. Cultures may strive to produce stone tools in uniform mental templates, but contextual factors such as raw material package size, abundance, and quality (Ashton and White 2003; Dibble 1995; Kuhn 1991) as well as circumstances of production such as anticipated or unanticipated tasks play a significant role in tool production and consumption processes (Tomka 2001; Wurz 2002). The cultural and cognitive linkages to tool production processes expressed in chaîne opératoire act to limit our ability to understand the contexts and situations that are so important for interpreting the conditions under which stone tools are produced. It is unrealistic to think that stone toolmakers and users were so welded to their cultural mode(s) of production that they could not adjust, adapt, or shift processes of tool production when the situation required it. I am not sure how to apply the cognitive values or information supposedly associated with the chaîne opératoire concept to stone tool analysis. To my knowledge, it has never been done outside of sweeping claims that contemporary researchers know or understand the mind or mental structures of ancient toolmakers because they have reconstructed operational chaînes of tool production.

My overall opinion on the concepts of reduction sequences and chaîne opératoire is that they are substantially the same things from an application perspective, and that both concepts are inclusive of the larger issues of procurement, manufacture, use, maintenance, and discard. That is, if researchers attempt to apply these concepts to stone tool assemblages, they both contribute similar kinds of features. Both concepts are easily connected to the larger issues of human land use related to environmental, social, and historical contexts. Clearly, both concepts recognize these larger contexts (Andrefsky 2007b; Bleed 2001; Clarkson 2002; Eren et al.

2005; Hiscock and Attenbrow 2006; Hiscock and Clarkson 2007; Nowell et al. 2003; Wilson and Andrefsky 2008). It is for these reasons that, regardless of the terms used, the production of tools and the reduction of cores are central to an understanding of lithic technological organization. We must realize that lithic retouch, whether it relates to tool production or maintenance, or the acquisition of blades and flakes, has much to do with the contexts of human land use; for this reason understanding reduction sequences and chaîne opératoire allows us to better understand lithic technological organization.

As lithic analysts begin thinking about the place of stone tools within the framework of life histories, we envision tools in multiple contexts. Stone tools are produced, used, maintained, reconfigured, discarded, reused, and ultimately discovered by archaeologists and others. These multiple contexts expand our understanding of stone tool retouch from simply the production contexts of tools to a more inclusive understanding of retouch contexts. Retouch of cores and tools includes not only the production stages of tool manufacture, but also the maintenance of tool edges after use to resharpen or reconfigure the specimen (Brantingham and Kuhn 2001; Flenniken and Raymond 1986; Hiscock and Attenbrow 2003; J. Morrow 1997; Nowell et al. 2003). In this context stone tools are shown to actually change shape and at times change functional uses as a direct result of tool maintenance (Andrefsky 2005; Bisson 2000; Hiscock and Clarkson 2008; McPherron 2003; Soriano et al. 2007; Tomaskova 2005; Weedman 2006). Within this framework of viewing stone tools as ever changing due to reduction, it is important to remember that retouch is performed for different reasons by toolmakers and users; tool retouch should not be viewed as a single uniform process with a single uniform function or meaning.

Recent investigations have shown that some stone tool types such as flake knives have no separate production and use phases. Such tools are retouched as needed, resulting in morphological transformation during the process of use and resharpening (Clarkson 2002; Dibble 1987; Rolland and Dibble 1990). Other stone tool types such as projectile points have very discrete production and use phases, where they are not used until after they have gone through a formal production process (Andrefsky 2006, 2008c; Wilson and Andrefsky 2008). Even though stone tools such as projectile points undergo morphological transformation in both the production and use phases as a result of retouch, the production phase is not a good measure of tool use. If researchers are interested in measuring stone tool use, it becomes important to discriminate between different kinds of retouch. This is particularly relevant for researchers interested in tool retouch as a proxy for artifact curation.

Many of the traditional notions of what a temporally “diagnostic” stone tool assemblage is or is not have been debunked by recent investigations dealing with core reduction and tool production models (Dibble 1995; Hiscock 1996; Holdaway et al. 1996; McPherron 2000). Recently, Hiscock and Attenbrow (2003) tested the viability of early Australian diagnostic implement types when compared to measures of reduction. In doing so, they developed two simple yet effective measures of stone tool retouch that appear to be useful for all flaked stone tool forms with a steep (scraperlike) cutting edge. The first was the retouch perimeter index, which was simply a ratio of the retouched edge relative to the total flake tool edge. Values closer to “0” have very little retouch and values approaching “1” have extensive amounts of retouch. This retouch perimeter index correlated positively with Kuhn’s (1990) index of retouch, when it was averaged at three places on the stone tool (average Kuhn index) (Hiscock and Attenbrow 2003, p. 243). They also measured the extent of retouch at various locations on the tool by partitioning the tool into eight segments and noting the number of segments containing retouch. Interestingly, this too correlated positively with Kuhn’s average retouch index, suggesting that more areas of the tool became retouched as the amount of retouch increased on a flake tool. Finally, Hiscock and Attenbrow (2003, p. 246) characterized the shape of the retouched edge with a new measure (index of retouch curvature), showing that as retouch intensity increased the retouched edge became more curved. This index was calculated by simply expressing the extent of concavity or convexity of the edge relative to the distance between the ends of the retouch (see Fig. 2 in Hiscock and Attenbrow 2003). Positive values for retouch curvature index indicate convex edges, negative values indicate concave retouched edges, and a value of “0” indicates a straight retouched edge.

Hiscock and Attenbrow (2003) ultimately showed that retouch amount and shape are continuous rather than discontinuous on scraper tools from this assemblage. They also showed that morphological variation used to identify previous types of scrapers was essentially directly associated with differences in the extent of retouch. All variations in scraper morphology could, in fact, be associated with differences in retouch amount, and this could explain all recognized forms or types. The technological decisions to pursue greater or lesser amounts of retouch (the user decision-making strategies) might have more to do with economic, social, or environmental factors as opposed to cognitive processes to pursue various shapes of tools.

Curation and lithic technological organization

Binford (1973, 1979) introduced the curation concept to hunter-gatherer archaeology in the 1970s. His ideas were followed by a great deal of exploration, discussion, and excitement on the part of archaeologists interested in lithic analysis (Bamforth 1986; Bleed 1986; Chatters 1987; Close 1996; Gramly 1980; Nash 1996; Odell 1996a). One reason for so much discussion on the curation concept by archaeologists was Binford’s complicated way of using the term. In my opinion it was complicated because he did not provide a strict definition and instead used the term in association with a number of interesting ideas. For instance, Binford (1973) discussed curation in the context of artifacts being transported from one location to another in anticipation of tasks to be completed at the new location. For some archaeologists curation became associated with transported tools (Bettinger 1987; Gramly 1980; Nelson 1991). In the same paper, Binford also linked curation to efficiency of tool use. Bamforth’s (1986) paper on technological efficiency and tool curation expanded this concept to include five aspects of tool curation: (1) production in advance of use; (2) implement designs for multiple uses; (3) transport of tools to multiple locations; (4) maintenance of tools; and (5) recycling of tools. Stone tools do not have to contain all five aspects to be considered curated specimens (Bamforth 1986). The notion of tool production effort was added to the definition in the form of complex tools or tools with haft elements or complex flaking patterns (Andrefsky 1994a; Hayden 1993; Parry and Kelly 1987). In a review of the curation concept, Odell (1996b, p. 75) concludes that for the term "curation" to be useful, "…the most parsimonious usage would retain those elements associated with mobility and settlement, and discard the ones associated with tool conservation." Nash's review of the curation concept concludes that the term is ill-defined but already embedded in the literature: "In the absence of such standardization, we should drop the term from the archaeological literature all together" (Nash 1966, p. 96). Shott (1996, p. 267) suggests that curation is not a state, condition, or qualitative strategy, but a relationship between things; curation is not transport, efficiency, recycling, use life, or anticipation of use, although the curation process may have such qualities (pp. 264–265).

Part of the reason Binford's ideas on curation received so much attention was because they linked stone tools to human mobility patterns (Bamforth 1990; Kelly 1983, 1988; Lurie 1989; Shott 1986; Torrence 1983). Mobility patterns were recognized as an integral part of human technological organization (Binford 1979, 1980; Nelson 1991). Some of the early lithic analytical practitioners of the curation concept contrasted "curated tools" with "expedient tools" (Andrefsky 1991; Bamforth 1986; Kelly 1988; Parry and Kelly 1987). In these studies lithic tools were often pigeonholed on either end of a retouch spectrum. "Curated" tools were often recognized as having extensive retouch, and "expedient" tools were recognized as having very little retouch. This simple way of viewing retouch on tools was sometimes superposed over Binford's model of hunter-gatherer land use as either being associated with foragers or collectors, with foragers being residentially mobile and collectors being residentially sedentary or semisedentary. As it turns out, "curated" tools were often associated with foragers, and "expedient" tools were often associated with collectors. This kind of stone tool classification is still popular in the literature; however, many lithic analysts realized that this one-to-one relationship is not realistic and that stone tool configuration is influenced by many other factors such as raw material availability, shape, and function (Andrefsky 1994a, b; Bamforth 1991; Bradbury and Franklin 2000; Kuhn 1991; MacDonald 2008; Wallace and Shea 2006).

Early studies of stone tool curation viewed curation as a tool type. Stone tools were recognized as either curated or not curated. I find the curation concept unworkable as a tool type and follow other researchers in recognizing curation as a process associated with tool use. To effectively use the concept of curation within the context of technological organization, I recognize it as a process reflecting a tool's actual use relative to its maximum potential use (Andrefsky 2006, 2008b; Shott 1996; Shott and Sillitoe 2004, 2005). There are only tools in various phases of being curated from very low use relative to maximum potential use to very high use relative to maximum potential use. In this regard curation may be measured from low to high, allowing investigators to plug curation into models of human organizational strategies.

Stone tool curation should not be confused with the “use life” of a tool, which is simply the length of service for which a tool is adopted (Andrefsky 2006, 2008b; Shott and Sillitoe 2005). This implies that a tool with a great deal of retouch present on its surface (such as a Folsom point) might have a low curation value as compared to a nonretouched flake tool that was discarded shortly after becoming dull from quick use as a wood whittling tool. In this case the Folsom point might have had a longer use life than the flake tool, but it was less curated because its actual use relative to its maximum potential use was not realized. The flake tool, on the other hand, may have been discarded immediately after it became dull from use. In this sense the flake tool was heavily curated (all used up), even though it had a very short use life. By keeping the curation concept separate from the use life concept, it becomes easier to understand the role of lithic raw material abundance and availability in the configuration of stone tools and the deposition of stone tool assemblages at particular locations. Both concepts play an important part in our understanding of how humans organize themselves with regard to lithic technology and other economic and environmental factors. So how can researchers recognize and measure curation on stone tools?

Recognizing and quantifying curation

If stone tool curation is defined as the process reflecting a tool’s actual use relative to its maximum potential use, then it would be important to get some measure of tool use as a proxy for curation. Early research efforts dealt with measuring retouch on tool edges. For instance, Wilmsen (1970) estimated retouch based on the length of the tool’s edge; Barton (1988) estimated the length of the retouched tool edge; Close (1991) measured the depth of retouch on the tool margin. These techniques were influenced by tool size, making them difficult to use on diverse tool forms. Grimes and Grimes’ (1985) technique to measure retouch actually measured the amount of length remaining on used tools. This, like some of the other early techniques, did not measure the extent of prior use, only the amount of potential use left in the tool at discard. Given our definition of curation, one effective way to assess curation would be to initially determine the size of an unused blank and then compare that size to the size of the actual tool recovered. Several techniques have been developed to estimate initial size of flake blanks based on allometric relationships among flake variables (Dibble 1997; Eren and Prendergast 2008; Odell 1989; Pelcin 1997; Quinn et al. 2008; Wurz et al. 2003). Allometric methods rely on the size relationships or properties among tool dimensions. For instance, if characteristics such as original flake mass and/or weight are correlated with original striking platform width, researchers might be able to estimate original flake mass even after most of the original mass has been eliminated by retouch, provided that the original striking platform is available for measurement. Similarly, some types of stone tools, by their nature, are retouched on the blade or bit element and not on their handle or haft element. In such cases, if the original haft element size is correlated with blade element size, the original blade element size can be estimated from the haft element even after the blade has been reduced by retouch (Andrefsky 2006; Hoffman 1985; Shott and Ballenger 2007).

Dibble and Pelcin (1995) were among the first to use allometry of flake characteristics to estimate original flake blank size in the context of artifact curation. Their thesis showed that exterior platform angle and platform thickness were predictors of original flake mass. As such, estimated original flake mass could be compared to flake mass of recovered tools to infer extent of retouch and ultimately amount of artifact curation for specific tools. Davis and Shea (1998) tested this relationship and found it to be correct to a certain extent but they found that these two platform attributes consistently underestimated original flake mass. This test was challenged by Dibble (1998) and again by Pelcin (1998). Shott et al. (2000) waded into the discussion with new experiments and analyses. They suggest that platform attributes do predict original flake size but only under stringent assumptions related to platform variables and that such an allometric relationship is effective only when examining flakes produced from hard-hammer percussion and not soft-hammer percussion. Assessing stone tool retouch by estimating original blank size is potentially one of the most effective ways to approach curation analysis. Such estimates, however, also are subject to great error given the assumptions needed for estimating original blank sizes in some cases (Eren et al. 2005; Shott et al. 2000). It has been shown that even factors such as variability in lithic raw material composition can influence the effective predictability of original flake blank sizes (Bradbury et al. 2008).

There have been a number of innovative and effective retouch measures developed for unifacial flake tools that do not necessarily rely on estimates of the original flake blank size (Blades 2003; Dibble 1995; Jefferies 1990; Kuhn 1990, 1992; J. Morrow 1997; Weedman 2002). Kuhn's geometric index has been tested and appears to be an especially effective technique for measuring end scraper retouch (Eren and Prendergast 2008; Hiscock and Attenbrow 2003; Hiscock and Clarkson 2005). This index is basically calculated as the ratio between the worked face of a scraper edge and the maximum thickness of the flake blank. The logic behind this index rests with the notion that as the retouched surface of the scraper is resharpened, the face of the tool gets larger, until ultimately it is equal to the thickest part of the tool (see Figs. 1 and 2 in Kuhn 1990). Tools of different sizes can be compared to one another because the index is based on the ratio derived from the attributes, which scale the measure from "0" to "1." Since all scraper working edges have an angle that makes them less than 90°, Kuhn (1990, p. 585) also adds this angle to the index calculation to measure more accurately the amount of use the scraper has undergone.

One of the drawbacks to Kuhn's geometric index is that it is designed for scraping tools. Flake tools that are not sharpened with one edge moving progressively toward the center of the tool cannot be assessed effectively by this index. Furthermore, this index assumes that the original blank shape is not thickest on the original scraper cutting edge (usually the distal end of the flake blank). Scrapers that are made from blanks that have cutting edges that begin on the thickest section of the flake blank, such as scrapers made on plunging flakes, will have a geometric index value of "1" immediately upon initial manufacture. A value of "1" suggests a great amount of retouch and ultimately a great amount of use for the scraper, even before the scraper is used. This renders the geometric index ineffective for assessing curation amount on flake tools made on flake blanks that are at their thickest point near their edges or margins. Others have suggested that Kuhn's geometric index can be expanded upon to account for three instead of two dimensions, thus making for a more accurate indicator of retouch and curation on scrapers made on various flake blank forms (Eren et al. 2005). Kuhn's method, however, is generally an accurate indicator of scraper use and provides a good proxy measure for curation (Hiscock and Attenbrow 2003; Hiscock and Clarkson 2005), but it is effective only for scrapers with a triangular cross section.

Another effective technique to measure retouch and subsequently curation amount is Clarkson's index of invasiveness (Clarkson 2002; Hiscock and Clarkson 2008). This technique measures retouch on all flake tool types regardless of whether they are retouched unifacially or bifacially. This technique partitions the flake tool into eight zones on both the dorsal and ventral surfaces, for a total of 16 zones, and assesses the extent to which flake scars invade the tool from the edge to the middle. Each zone is scored with values of "0" for no retouch in the zone, "0.5" if flake scars reach only into the outer margin of the tool, and "1.0" if the flake scar reaches into the inner part of the tool face (see Fig. 2 in Clarkson 2002). All zone scores are then summed and divided by the total number of zones (16) to produce an index between "0" (no retouch) and "1" (completely retouched). This index is an excellent technique for obtaining a measure of retouch on flake tools, both unifacial and bifacial. However, this index of invasiveness is designed for flakes that are used as cutting or scraping tools and then are progressively retouched to resharpen a dulled edge. Ultimately, extensive resharpening on both surfaces can create a bifacially retouched tool. Such tools have high index values reflecting more retouching, more use, and ultimately more curation. However, some bifaces such as hafted bifaces and projectile points from North America were not designed in this manner. North American hafted bifaces were completely retouched on both sides during the production and shaping process, often before ever being used (Andrefsky 2006; Callahan 1979; Whittaker 1994). Application of the index of invasiveness to these kinds of tools would produce a high index value that suggests high curation amounts even though the specimen may have never been used, which is contrary to my working definition of curation. Retouch on North American projectile points and hafted bifaces also does occur after use, but unlike flake tools that "evolve" into bifaces after having been retouched extensively after use, hafted bifaces are retouched only on their blade elements and not on their haft elements (Andrefsky 1997; Flenniken and Wilke 1989; Goodyear 1979; Truncer 1990).

Measuring retouch on hafted bifaces and projectile points also is very important for assessing curation and for understanding how lithic technology is organized. Bifaces have long been used as indicators for lithic technological organization (Andrefsky 1994a, 1995; Bamforth 2003; Bamforth and Becker 2000; Kelly 1988; Kelly and Todd 1988; Sellet 2004; Soressi and Hays 2003). However, as noted above, bifaces undergo a production phase that is discrete from a use phase. Tool curation deals with tool use. Hafted biface use is reflected in retouch that has taken place on the "business end" of the tool, the blade element. Recently, several studies of hafted biface and projectile point retouch have attempted to explain the phases of production and maintenance after use in the context of tool curation (Andrefsky

2006; Shott and Ballenger 2007; Wilson and Andrefsky 2008). Similar to Clarkson's index of invasiveness (Clarkson 2002), Andrefsky's (2006) hafted biface retouch index partitions the specimen (blade element only) into 16 segments and records a retouch value for each segment. Retouch values for each segment are summed and divided by the total number of segments to acquire an index score ranging from "0" (no retouch) to "1" (greatest amount of retouch) (see Figs. 1 and 2 in Andrefsky 2006). Even though the hafted biface retouch index provides a comparable score so that retouch can be compared to all sizes and types of hafted bifaces, highly resharpened hafted bifaces—those approaching diamond-shaped cross sections—tend to be assessed less effectively with this technique. I also would suggest that researchers can increase their precision in measuring retouch with this index, if that is desirable, by first sorting hafted bifaces into known types or styles.

One of the important things that we are beginning to learn from studies of stone tool retouch is that measures of curation may not be, nor should we expect them to be, universal to all tool types (Andrefsky 2006, 2008c; Quinn et al. 2008; Wilson and Andrefsky 2008). Measures of retouch used to assess artifact curation must be intimately associated with characteristics such as artifact type and potential artifact function, and even to extramural agencies such as lithic raw material abundance and quality. It is becoming increasingly clear that these various contextual influences are extremely important on retouch measures as it relates to the concept of artifact curation.

Raw materials and organizational choices

Hunter-gatherer organizational strategies and lithic technology were featured in a series of papers that debate embedded versus direct procurement of tool stone by toolmakers (Binford 1973, 1985; Binford and Stone 1985; Gould 1985; Gould and Saggers 1985). Even though the importance of lithic raw material availability is well known by those studying known toolmakers (Binford 1986; Gould 1980; O'Connell 1977; Takase 2004; Weedman 2006), this debate signaled the importance of lithic raw material availability to many archaeologists studying stone tools made by ancient aboriginal populations (Amick 1999; Andrefsky 1994a; Bamforth 1986; Bar-Yosef 1991; Dibble 1991; Goodyear 1993; Jelinek 1991; Morrow and Jefferies 1989; Wiant and Hassen 1985). Next to diamond, silicified stone is the hardest material found on the planet. It breaks conchoidally and is brittle enough to be manipulated into different shapes with sharp edges. The distribution and availability of lithic raw materials are undeniably important in stipulating how humans manufactured, used, and reconfigured stone tools. Because lithic raw materials can often be sourced, they provide robust information about circulation of stone, if not people, across the landscape. This fact alone makes lithic raw material an important resource for gaining insight into human land use and mobility patterns, and relating those to lithic technology.

Some simulation studies have shown that the distribution of lithic raw materials may simply be a function of random encounters with stone sources in the environment, and that raw material procurement may not be linked to human organizational strategies in any substantial way (Brantingham 2003). Despite the potential that raw material procurement may have no or very little influence on hunter-gatherer technological organization, which I doubt is the case, recent research indicates that lithic raw materials are important for determining tool and core technological strategies (Ashton and White 2003; Brantingham and Kuhn 2001; Roth and Dibble 1998; Wenzel and Shelley 2001), artifact functional effectiveness (Bamforth 2003; Brantingham et al. 2000; Hofman 2003; Sievert and Wise 2001; Terry et al. 2008), retouch intensity on tools (Andrefsky 2008c; Bradbury et al. 2008; Kuhn 1992; MacDonald 2008; Milliken and Peresani 1998), and aspects of risk management (Baales 2001; Beck et al. 2002; Braun 2005; Lee and Lee 2006; Soressi and Hays 2003). If anything, the information gained from lithic raw materials regarding source location, shape, size, durability, and abundance has increased our understanding of stone tool technological organization in the past decade.

For instance, in a study of core reduction strategies, Braun (2005) evaluates the degree to which different core technologies conserve raw material given differences in raw material availability at various locations. Similar studies have been conducted, but usually through experimental replication of different core technologies, measuring usable edges or the amount of potential usable materials (Bradbury and Franklin 2000; Prasciunas 2007; Rasic and Andrefsky 2001). Braun tests the influence of raw material variability against the archaeological record from the Middle Paleolithic in southwest Asia. His study shows that stone toolmakers elected to conserve raw material in the face of lithic resource constraints by changing technological strategies (Braun 2005). In doing so, he developed a conservation index that provides a model for the number of flakes produced from a core of given mass (see Fig. 8 in Braun 2005). Brantingham and Kuhn (2001) obtained similar results when they modeled Levallois core technology for efficiency and effectiveness: Levallois cores were relatively efficient at minimizing raw material waste while at the same time maximizing productivity in terms of the number of usable tools produced. In essence, Levallois technology may have been selected as a strategy of retouch as a raw material conservation technique. This emphasizes the importance of economic constraints on stone tool production strategies.

Researchers have suggested that raw material types may be differentially effective for different functions and tasks (Frison 1991; Greiser and Sheets 1979; Knecht 1997). In a study comparing the effectiveness of retouching different stone types, Bradbury et al. (2008) found that raw material types fractured with significant differences. They developed analytical models to predict original flake blank mass from retouch debitage; each raw material type required separate equations to predict original blank size because retouch debitage variability was most sensitive to lithic raw material type. This suggests that different lithic raw material types have different fracture properties and different amounts of brittleness and durability. Terry et al. (2008) also found that raw material type tended to significantly vary with regard to different tool forms during the Upper Paleolithic in the Transbaikal region of Siberia. Thinking that these raw material differences might be related to raw material effectiveness for task completion, they established a set of experiments to test the effectiveness of scraping and cutting different densities of wood. They found that extremely glassy cryptocrystalline chert was less effective for heavy-duty scraping than were more coarsely textured igneous rocks (Terry et al. 2008). These results strongly suggest that lithic raw material types can be important for different functions and need to be considered in scenarios of technological organization.

Raw material proximity also has been shown to influence the degree to which stone tools are retouched. At a forager residence site in the Great Basin area of the U.S., I show that lithic raw materials are readily available to toolmakers and that hafted bifaces tend to be discarded and not resharpened after impact damage if foragers are within two days travel distance from their residence location (Andrefsky 2008c). However, if the toolmakers are more than a two-day distance from their residences while foraging, they will reconfigure broken hafted bifaces used as projectiles and resharpen dulled hafted bifaces used as knives. Lithic raw material source areas defined by X-ray fluorescence (XRF) were effective in determining precise distances from each source to the residence base. Retouch intensity on hafted bifaces was shown to directly correlate with these defined distances and proximity to each source.

Kuhn's (1991) study of Mousterian technology in Italy also explored the role of raw material on tool retouch intensity. Interestingly, Kuhn showed that lithic raw material availability and size were important for determining the type of core technology employed and how extensively cores were reduced. Raw material availability, however, was not important for determining the extent to which tools were retouched; instead, retouch was linked to some factor other than raw material availability (Kuhn 1991, 1995).

All of these studies show that lithic raw materials play an important role in the organization of technology. Yet it is apparent that raw material availability, size, and quality have complex influences on different aspects of stone tool technology. Core reduction technologies, whether they are bipolar, bifacial, or unidirectional, are impacted differently than stone tool retouch when it comes to lithic raw material influences. Similarly, researchers must account for effectiveness of different raw material types in performance of different tasks given all else being equal.

The good, the bad, the ugly: Raw material provenience

The section above demonstrates the value of understanding lithic raw material source locations within the context of human organizational studies. However, not all stone can be sourced with the same amount of confidence. Archaeologists often observe stone color, texture, luster, inclusions, fossils, and phenocrysts among other macroscopic attributes to assess stone source locations. Unfortunately, even though such provenience designations may be correct, they are sometimes not useful for determining aspects of technological organization since many tool stone types form over very large expanses of territory (in the neighborhood of hundreds or thousands of square kilometers). Such tool stone is often formed from a sedimentary parent material that had a genesis at the bottom of large inland seas or oceans. To say, for example, that a projectile point is made from Edward's Plateau chert is to say that the stone may have come from outcrops and exposures in any one of hundreds of places over thousands of square kilometers. Such gross locational information may not be useful for archaeologists interested in understanding land-use patterns of Middle Archaic aboriginal folks in a small area of central Texas where the Edward's Plateau chert is ubiquitously found.

A series of geochemical techniques have been developed to gain more precision with lithic raw material provenience studies. Geochemical techniques are used to determine the elemental composition of rock. Such techniques provide the relative proportion of different elements found in rock. These proportions compare the elemental composition of lithic artifacts to various rock samples from known source locations in an effort to associate artifacts to sources with some level of confidence. There are several techniques of geochemical analysis, and each provides different kinds of information about chemical signatures. There are a number of different references that describe some of the more traditional techniques (Andrefsky 2005; Kooyman 2000; Odell 2004; Shackley 1998a). In all cases geochemical sourcing provides only the composition of a range of elements in the archaeological sample. To make provenience associations, the sources of parent rock also must have been geochemically assessed. It is often the case that archaeological samples have geochemical signatures that do not match known sources of stone.

Obsidian sources have been widely assessed geochemically and have proven to be fairly reliably linked to archaeological specimens (Bayman and Shackley 1999; Eerkens and Glascock 2000; Eerkens et al. 2007; Ferguson and Skinner 2005; Glascock et al. 1994; Hughes 1998; Negash et al. 2006, 2007; Roth 2000; Shackley 1998b, 2005; Stoltman and Hughes 2004; Tykot 2002, 2003). Some obsidian provenience studies have been able to reliably recognize "subsources" of obsidian and have shown that these sources provide useful information related to human land-use practices (Eerkens and Rosenthal 2004; Young 2002). Classic geochemical compositional analysis such as X-ray fluorescence, instrumental neutron activation analysis (INAA), particle-induced X-ray emission analysis (PIXIE), and others have been successful for obsidian source studies, not only because obsidian flows are easily recognized and then tested for a signature, but also because the relatively fast solidification of molten rock creates a diagnostic array of minerals that results in diagnostic elemental signatures. This is why other igneous rock such as dacites and basalts also can be geochemically linked to discrete locations (Bakewell 2003; Waechter 2002); it is the same reason that tool stones that originate from massive sedimentary parent sources cannot be geochemically linked to discrete locations.

Most stone tools on a worldwide basis are made from cherts. Luedtke (1992) and Andrefsky (2005) provide justification and definitions for this rock term to include all cryptocrystalline silicates having genesis from a sedimentary parent material. Cherts, unlike obsidian and some other igneous rock, undergo multiple phases of genesis and reconfiguration of minerals during their formation. Often this occurs over great expanses of ocean bottom, resulting in a very nondiagnostic geographic geochemical signature for cherts. In other words, there can be more geochemical variation within chert samples than between chert samples. This does not mean that geochemical analysis cannot be performed on chert (Hess 1996; Hoard et al. 1992, 1993; Malyk-Selivanova et al. 1998); it simply means that the geochemical signature from a lithic artifact often cannot be reliably associated with one particular source location.

Some progress is being made along these lines. Foradas (2003) has focused on authigenic biogenic minerals when using geochemical techniques to assess chert. Authigenic minerals are relatively immobile in chert during diagenesis (compared to secondary minerals such as Ca, Mn, Sr, Mg, P). Authigenic biogenic minerals reflect variation in the abundance of calcareous and siliceous marine organisms in the environment of deposition. If such organisms have a restricted geographic range in the larger depositional environment, there is a chance that this can be expressed as a diagnostic locational signature after cherts are formed. Foradas (2003) has made some progress with chert sources of Ohio Hopewell blades being restricted locations within a Pennsylvanian Age stratum of sedimentary rock, but more testing is needed.

There also is the possibility that geochemical methods will be helpful in determining chert provenience on those materials that have undergone relatively isolated genesis due to silica precipitation from unique sources, such as volcanic vents pushing through sedimentary deposits. Lyons et al. (2003) have demonstrated chert source differences in southeastern Oregon using INAA assessment. Some of their study area contains Miocene sediments blown into the region from volcanic vents. These sediments were truncated by a series of fissure eruptions of basaltic lava in the late Miocene, which created isolated occurrences of chert (Orr et al. 1999). In such situations it is reasonable to expect that chert might have diagnostic geochemical signatures due to its unique and relatively rapid formation associated with fissure eruptions.

Recently, there have been other techniques used to assess chert provenience related to its luminescence properties. One popular technique used by some archaeologists is to view chert samples under ultraviolet light and observe the amount of fluorescence emitted from the specimen (Banks 1990; Church 1990; Elston 1992; Hofman et al. 1991; Lyons et al. 2003). Use of ultraviolet light to recognize chert has been shown to be problematic because of the effects of different UV lights and because of the difficulty in describing the visible fluorescence emitted from the sample (Church 1994). Other more promising techniques used to measure luminescence in rock include cathodoluminescence (CL) analysis (Dietrich and Grant 1985; Marshall 1988) and thermoluminescence (TL) analysis (Prescott and Robertson 1997; Roberts 1997). Both techniques have recently been described by Akridge and Benoit (2001) as they explored their use on samples of chert. CL measures the emission of light from a sample during bombardment with energetic electrons; the amount of orange-colored emitted light appears to be a good gauge for the abundance of carbonates in chert. TL measures the emission of light during heating of the chert samples, a proxy for the thermal and radiation exposure history of the specimen. Akridge and Benoit (2001) found that TL is a good gauge for quartz crystallinity or quartz grain size and could be useful for helping derive diagnostic signatures for chert specimens if used with other techniques.

Clearly, provenience studies of lithic raw materials is complicated and requires multiple techniques to arrive at the most reliable estimate of artifact source location. This complexity relates primarily to the manner in which usable tool stone is formed. Those tool stone types that have relatively less complicated formation processes, such as obsidian, appear to be more reliably linked to sources using geochemical techniques. Cherts are less reliably linked to source areas because chert source areas are often extremely vast and because chert tends to have a great amount of within-sample chemical variability relative to between-sample chemical variability. Archaeologists are slowly adopting new techniques to help understand the nature and origins of this variability.

Debitage individuals and aggregates

It is important to understand that investigators not only examine lithic tools for evidence of sequential removal of detached pieces, but they also study the detached pieces (debitage and debris) themselves in an effort to gain insight into tool production and core reduction activities (Andrefsky 2001b; Bradbury and Carr 1999; Carr and Bradbury 2001; Kalin 1981; Odell 1989; Rasic and Andrefsky 2001). Debitage is important because lithic analysts attempting to characterize the organization of lithic technology often do not have stone tools to study but only the remains of stone tool production and maintenance. Based partially on lithic raw material type analysis, we are fairly confident that stone tools are often made or retouched at one location and then transported to another location for additional use and/or discard. This presents quite a problem if the researcher is interested in characterizing lithic technology across the landscape. In the 1970s and 1980s several archaeologists began following Crabtree's (1972) advice and began looking at stone tool production debitage as a proxy for stone tool production activities (Amick and Mauldin 1989; Amick et al. 1988; Ammerman and Andrefsky 1982; Andrefsky 1986; Ingbar et al. 1989; Magne and Pokotylo 1981; Patterson and Sollberger 1978; Sullivan and Rozen 1985).

Recent studies of lithic debitage have examined the source of variation in debitage characteristics in an effort to link those characteristics to broader issues of technological practices. For instance, a series of studies has examined the relationship between debitage striking platform angles to original flake size and production technology (Cochrane 2003; Davis and Shea 1998; Dibble 1997; Pelcin 1997; Shott et al. 2000). This analysis is proving to be quite promising. Others have used debitage sizes to help determine aboriginal land-use practices (Baumler and Davis 2004; Eerkens et al. 2007). Inferences derived from debitage are often made from a population or assemblage of debitage specimens. Recent investigations suggest that single debitage specimens can provide powerful technological information. Debitage typologies have been described that explicitly link single debitage specimens to specific technologies such as bifacial trimming, end-scraper resharpening, projectile point notching, and bipolar reduction (Andrefsky 2005; Root 2004; Titmus 1985). Other debitage studies have been effective for determining artifact types produced and kind of technology practiced at a site (Dibble and Pelcin 1995; Kuijt et al. 1995; Moore 2002; Patterson 1990) and have even provided information on site formation processes (Clark 1991; Fladmark 1982; Hull 1987; Nadel 2001; Shafer 1991; Shafer and Hester 1983). The information gleaned from lithic debitage analysis has been very important in linking lithic technology to human organizational strategies used by aboriginal toolmakers.

One type of debitage analysis known as "mass analysis" has been widely adopted by researchers to make inferences on stone tool production activities (Ahler 1989; Ahler and Christenson 1983; Baumler and Davis 2000, 2004; Baumler and Downum 1989; Carr and Bradbury 2001, 2004; Root 1992). Part of the reason mass analysis has been so appealing to researchers relates to the relative ease and speed with which it can process large quantities of debitage. According to Ahler (1989), mass analysis does not require handling or measuring individual specimens, it can be applied to the full range of debitage without regard to shape or relative completeness of specimens, and it is highly objective since analysis is conducted by sifting debitage through various screen sizes. It is easy to understand the appeal of mass analysis as an analytical strategy given these characteristics of the technique. Mass analysis is a form of debitage population study that assimilates all debitage within a recognized assemblage or population and segregates it into size groups known as "size grades." Based on the relative proportion of debitage within each size grade, generalizations are made about the technology used to produce the debitage population. The relative proportion of size grades is established by the count and weight of specimens in each size grade. The average weight of each size grade and the percentage of specimens with cortex in each size grade also may be calculated. These proportions and average values become the attributes of the debitage population used in mass analysis techniques.

One of the most popular ways to stratify debitage into size grades is to sift the debitage through a series of nested screens. Assessing debitage sizes by screen sifting is not restricted to mass analysis (Henry et al. 1976; Kalin 1981; Patterson 1990); however, mass analysis has popularized this type of size segregation. The investigator can save a considerable amount of time using this technique because she or he is not required to separate the debitage into whole or broken flakes or shatter or platform remnant flakes. All debitage is shifted through the screens regardless of technological variety or completeness to arrive at size groups or size grades. A fairly untrained technician can do this sorting.

Interpretations about the excavated debitage population are generated by a "control group" of debitage based upon experimental replication of various tools or stages of core reduction. For instance, the investigator might replicate a biface from a flake blank or cobble. The debitage from that replication event is sorted into size grades and relative amounts of each size grade are calculated based on counts and weights and/or cortical representation. This control group is summarized to produce a signature of some type, such as a histogram, ratio measure, or a discriminant function. This control group signature is then compared to the signature obtained from the excavated collection using the same size grades. If the two signatures match, the investigator may infer that a biface was manufactured at that location, even if one was not found there. This type of debitage analysis is not only relatively easy to perform on a large number of specimens, it also provides much needed information about tool production activities or even tool resharpening activities at site locations when the tools themselves are either not recovered or have been carried away by aboriginal tool users. Multiple experimental replications can be conducted to evaluate all sizes of debitage resulting from the production of different kinds of stone tools and stages of stone tool reduction. These experimentally derived debitage signatures can then used as a reference library for various kinds of tool production or core reduction activities. For example, a specific debitage signature has been produced for hard-hammer reduction of cobbles, for bipolar reduction of pebbles, for projectile point manufacture, and even for the initial thinning of bifaces from flake blanks (Ahler 1989; Baumler and Downum 1989; J. Morrow 1997).

Recently, several investigators have begun testing the reliability of mass analysis for making interpretations of technological production activities. Studies assessing mass analysis emphasize that it is subject to multiple sources of error. It is apparent that size grades based on multiple screen sizes are not as objective as we once believed (Andrefsky 2005; Root 2004; Scott 1991). Debitage size varies based on shape, and standardized mesh does not control for debitage shape. This often results in debitage of different overall sizes getting combined together into the same size grade. It also has been shown that debitage variability is often a direct result of individual toolmaker differences (Gilreath 1984; Olausson 1998; Redman 1998; Shelley 1990). I found that even relatively simple technology, such as bipolar reduction, produces significantly different debitage size grade signatures when using mass analysis techniques (Andrefsky 2007a). Variability in raw material type as well as core size and shape has been shown to produce significant differences in debitage size grades (Bloomer and Ingbar 1992; Bradbury and Franklin 2000; Tomka 1989). These studies suggest that replication experiments conducted to produce controlled debitage data sets for mass analysis must begin with the same tool stone shape, size, and type as the excavated assemblage to make reliable comparative groups. Even when similar raw material composition is used, it often does not produce reliable production signatures (Andrefsky 2007a; Franklin and Simek 2001). Other studies have shown that even when the same toolmaker is making different tool types and controlling for raw material variability, mass analysis based on size-graded debitage does not reliably produce different signatures (Andrefsky 2007a; T. Morrow 1997). For these reasons mass analysis of debitage is not a reliable analytical strategy to infer the kinds of technology or the kind of tool produced at site location.

Even though debitage analysis can provide important clues to understanding the types of production and reduction technology that has taken place at a particular location, it is important to stratify the debitage assemblages into meaningful technological characteristics (Flenniken 1985; Root 2004; Titmus 1985) or production events (Andrefsky 2004; Carr and Bradbury 2004; Larson and Kornfeld 1997; T. Morrow 1997). It makes no sense to analyze an assemblage of debitage to determine the stages of tool production if that debitage assemblage is not initially separated into different technological types of debitage, such as bifacial trimming flakes, unifacial resharpening flakes, bipolar reduction flakes, and others that may be included in the assemblage. Each of these technologically different types has different metric properties related to tool production, such as size and cortex amount. An aggregate analysis of all debitage together would seriously compromise the results. Stated more strongly, use of pooled debitage from multiple production episodes or from different production technologies renders techniques such as mass analysis and other aggregate techniques ineffective for making technological inferences about human organizational strategies.

Nodules, puzzles, and pieces

In some regards the most reliable interpretations about stone tool production activities will come from sites where only one tool production or maintenance or function took place. When several activities occur at a site location, it becomes very difficult for the researcher to make reliable inferences about how the site was used. This is particularly true of site locations that were used for short periods of time over a very long time span as well as for site locations that were used intensively for multiple tasks and activities. One thing an investigator can do to sort out such a jumble of tools and debris in lithic assemblages is to partition the assemblage as finely as possible (Andrefsky 2004; Root 2004). For instance, it makes no sense to analyze debitage in an attempt to determine bifacial production stages or sequences at a site if the debitage being used is produced from a variety of tool production or core reduction activities such as bipolar reduction and end-scraper resharpening. If the investigator is interested in bifacial production activities that have taken place at the site, bifaces and/or bifacial debitage need to be examined. This is one of the reasons why mixed debitage assemblages are not suitable for techniques such as mass analysis based on screen-sized debitage.

One productive technique for assessing lithic artifact data into individual episodes of production, use, and maintenance is to refit chips onto tools and cores to reconstruct the original nodule or flake blank (Cziesla 1990; Hofman 1981; T. Morrow 1996; Simek 1994; Villa 1982). When a flake is rearticulated to a core or biface, there can be little doubt about the technological relationship between the two specimens. The issue of mixing individual production episodes can be addressed with refitting or conjoining detached pieces. Franklin and Simek (2001) used refitting analysis on a rock shelter assemblage from Tennessee to conclusively infer that bipolar technology had been used to test and reduce cobbles. Simek (1994) notes that refitting stone artifacts is a common analytical practice in parts of Europe (see also Grimm and Koetje 1992; Petraglia 1992; Veil 1990; Villa 1982). Archaeologists working in Japan also are actively refitting lithic assemblages (Bleed 2002a, b, 2004; Serizawa 1978).

Most artifact refit studies take place within single-site areas to interpret activities that have taken place within a camp. For instance, T. Morrow (1996) determined that the Twin Ditch site in the midwestern U.S. contained primary lithic production areas; it also contained debitage accumulations as a result of secondary refuse deposits or that the site area was cleaned by aboriginal inhabitants. Morrow also discovered that there was very little postdepositional site disturbance. Others have used artifact refitting to assess the integrity of occupational surfaces (Jodry 1992). Close (1996, 2000) advocates refitting at a regional scale to acquire “hard evidence” about prehistoric movements. For the most part, refitting can help investigators understand three primary aspects of site assemblages: (1) lithic technological practices that have occurred at a location, (2) taphonomic process at work (site integrity), and (3) spatial associations (Cooper and Qiu 2006; Larson and Ingbar 1992). With regard to lithic technological organization, we are primarily interested in the first aspect. Unfortunately, lithic artifact refitting can be very time consuming and often results in specimens that have no partners (Bamforth and Becker 2000; Bleed 2004; Hofman and Enloe 1992; T. Morrow 1996).

Recently, several researchers have begun to automate refitting efforts with the use of 3D modeling and visual technology (Riel-Salvatore et al. 2002). These efforts are still some distance from being operational and require sophisticated and expensive computer hardware and software. Another technique has been tested that uses standardized computer software available through GIS packages (Cooper and Qiu 2006). This technique does not actually attempt refitting digital images but instead uses raw material, distance, and artifact characteristics to narrow the field of potential specimens that might be candidates for a successful refit. Cooper and Qiu (2006) note that their GIS suitability model was able to identify known conjoinable pieces 32% of the time, when tested. Even though this does not sound like a very high success rate, it is actually much higher than what is expected through a process of pairwise comparisons of individual pieces. Unfortunately, this still left 68% of the known conjoinable pieces in the test to be sorted on a pairwise basis, and the 32% that were selected still needed to be compared to one another and refitted by hand. The bottom line is that this technique is still logistically time consuming.

Refitting analysis has recently been used to test the effectiveness of some linear regression models developed to predict core reduction and biface production sequences (Larson and Finley 2004). A refitted bifacial nodule from the Hell Gap site was used as an independent test of various flake attribute combinations. These were independently tested for predicting reduction sequences (Ingbar et al. 1989; Shott 1996). Regression models using flake attributes of the flake area (normal log) minus flake thickness (normal log) plus dorsal scar density (normal log) produced good predictability of bifacial core retouch sequences when compared to known flake refits (Larson and Finley 2004, p. 107); regression models using dorsal scar count minus flake weight (normal log) plus flake platform width (normal log and raw data) were found to be ineffective for predicting flake removal sequences. Larson and Finley's (2004) analysis was an innovative way to approach refitting analysis. They applied conjoined artifacts recovered from excavated sites as a test of analytical techniques derived from experimental replications used to infer lithic production and reduction strategies. This may prove to be an effective way to validate new analytical techniques outside of simply running quantitative tests of significance. Franklin and Simek (2001) conducted a similar exercise using refitting to assess the effectiveness of mass analysis.

One of the techniques introduced to partition lithic assemblages into separate production and maintenance episodes is minimal analytical nodule analysis (MANA) (Larson 1990, 1994; Larson and Kornfeld 1997). This term may have been used first by Kelly (1985) to describe "analytical nodules" of very similar kinds of raw material. Like refitting analysis, MANA begins by sorting the artifact assemblage into finely separated raw material varieties based on color, texture, crystalline inclusions, cortex, and other observable characteristics (including articulation of pieces). These finely sorted raw material groupings represent "analytical nodules" or populations that are segregated in the smallest related parts of a chipped stone assemblage short of refitting (Larson 1994). These "analytical nodules" are then assessed as individual populations to better understand site use and how technology is organized at the site. Some practitioners of MANA segregate each population into cores, tools, and debitage and, based on this classification, make interpretations about the flow of materials through a site (Hall 2004; Larson and Finley 2004; Larson and Kornfeld 1997). Others use MANA to infer production strategies at sites within each population to gain some idea of how different groups may have used the site location (Knell 2004, 2007; Sellet 1999).

MANA has been used to interpret projectile point production efforts on the Folsom component at the Agate Basin site in Wyoming. In this study Sellet (2004) formulated analytical nodules composed of channel flakes and flake fragments detached during the fluting process. Based on the number of proximal channel flake fragments and with some refitting evidence, he determined that 38 Folsom points were manufactured at the site even though no fluted point recovered at the site matched the discarded channel flakes with regard to raw materials type. The MANA strongly suggests that all manufactured points were removed from the site area. Outside of estimating point production efforts by Folsom-aged site occupants, the analysis suggests that the Agate Basin site was used as a location to "gear up" or manufacture new projectile points for future needs. Interestingly, at least seven different types of lithic raw materials were used to make, or at least to flute, Folsom points at the Agate Basis site, and most were from a source over 400 km away. This suggests that Folsom point technology is not necessarily linked to production at raw material quarries but is perhaps associated with other aspects of human adaptive strategies (Bamforth 2002; Hofman 1999; Ingbar and Hofman 1999). For instance, fluting of points might have been a late production step at camps just prior to organized hunts. In any case, lithic raw material proximity was not a significant part of Folsom technological organization at the Agate Basin site.

Once analytical nodules are segregated based on variants of raw material types, each analytical nodule is analyzed as to its constituent assemblage. Knell (2004, 2007) did this for the Cody Complex assemblages in the northern Plains of the U.S. Some analytical nodules might be associated with a technological trajectory encompassed under on-site tool manufacture, use, and discard. In this case the analytical nodule might include a used core, one or more flake tools created from the reduction of that core, and a suite of different sized debitage (Knell 2007, pp. 131–135). This might be in contrast to a technological trajectory where a finished tool is brought onto the site, used, resharpened, and then transported away from the site. In this case the analytical nodule might include only resharpening debitage (with no dorsal cortex), indicating that a finished tool was carried onto the site, used, and transported away from the site. If more detailed technological analysis is conducted on the debitage, the type of tool could be inferred.

By looking at each analytical nodule the investigator can characterize individual episodes of movement onto the site and travel away from the site. In this way more refined interpretations can be made about the organization of technological activities. Knell (2007) found that early Cody Complex occupants (Alberta Cody) were less focused on a core settlement area and appeared to be more geographically dispersed than later Cody Complex occupants (Localities I and V Cody Eden-Scottsbluff) of the site area.

MANA can provide a very detailed interpretation of the kinds of technological activities that have taken place at a site, and it is effective for comparing different site locations with regard to technological activities. Suppose that most "analytical nodules" at a site were present in the form of debitage only (no tools such as bifaces or cores). This would suggest that aboriginal site occupants were bringing finished tools onto the site, using them, resharpening them, and leaving with those tools. This pattern differs from one where debitage and bifaces were found at the site, which is suggestive of tool production activities (as opposed to simply tool maintenance activities). Should differences in the kinds of artifacts "dropped" at the site correspond to differences in "analytical nodules," it would be relatively easy to characterize different circulation patterns for site occupants. For these reasons, MANA represents a new and exciting type of lithic analytical strategy that relates to lithic technological organizational interpretations. It is important to remember, however, that MANA is most effective for internally heterogeneous categories of lithic raw materials. Those with great variability in color, texture, inclusions, etc., provide more reliable proxy data for actual production episodes. Homogeneous lithic raw materials are not suited for MANA because such materials tend to mix multiple potentially diverse technological assemblages (Ingbar et al. 1989; Larson 2004).

Departing thoughts

This article reviews literature on lithic analysis as it relates to activities of tool production, raw material procurement, and tool maintenance in the context of lithic technological organization. It is important to remember that lithic analysis refers to a method of comparing, assessing, and studying stone tools and debitage. To my knowledge there is no unifying theory associated with this archaeological data set. There have been recent attempts, however, to incorporate stone tool technology into behavioral ecological models of optimality (Bettinger et al. 2006; Elston and Brantingham 2002; Fitzhugh 2001; McCall 2007; Ugan et al. 2003). These efforts attempt to model technology as a cost within larger forager adaptive strategies. Although these efforts have been effective heuristically, such models have not been as successful with stone tool technology as have other kinds of archaeological material remains, such as faunal specimens with diet-breadth modeling. This is partly because stone tool technology does not have a single, easily measurable value. Almost all of the investigations reviewed above show that stone tools are dynamic in form and function and that they are deeply embedded with complicated systems of forager adaptive strategies. However, some applications are showing the potential of behavioral ecology to model and understand variability within lithic assemblages (Goodale et al. 2008).

Nevertheless, lithic analysts make inferences about past aboriginal behaviors and actions quite frequently based on the analysis of these kinds of remains. Such inferences are made primarily because researchers are able to make and evaluate predictions based on beliefs about the way lithic technology is organized within the lifeways of those who make and use stone tools. Does this constitute some kind of unifying theory for which we can interpret stone tools and debitage? Testable predictions or hypotheses are generated from two primary sources in scientific inquiry—theory and data patterning. Both allow researchers to make testable predictions. In my opinion, lithic technological organization has generated testable predictions about stone tools and human behavior from assumptions generated as a result of data patterns. We have not built or adopted a theory to help us generate consistently reliable predictions explicitly about stone technology. In fact, many of our predictions and assumptions related to stone tools, debitage, and human behavior have been found to be wrong. But I also believe that we are gradually gaining a better understanding of the relationships among stone tools, debitage, and human organizational choices. Described below are some new perspectives, given what has been reviewed above.

The recent literature on lithic analysis dealing with stone tool production and maintenance has dispelled some of our long-held ideas about lithic technological organization. I think we have been wrestling with the artifact curation concept and not making much traction because many of us did not have a good working definition of artifact curation. If we view artifact curation as a process that reflects the amount of tool use relative to the tool's maximum potential use, it is easy to understand that there are no curated tool types (as opposed to noncurated tool types), and that it does not make sense to contrast "curated" tools to "expedient" tools. Curation is a value, not a type. Expediently made tools may be (or may not be) more highly curated than complex formalized tools. Such curation values remain to be measured on individual tools. Similarly, any two formalized tools, such as Dalton projectile points, may have completely different values for curation amount.

Since curation is a process relevant to tools, it must be measured initially on tools. Some of the more recent literature has focused on new and interesting ways to actually measure curation on different tool types. In reviewing this literature, it has become apparent that not all measures of tool retouch are related to tool curation. Retouch does not always relate to tool use and, indeed, may relate to tool production before use. Tool curation relates to retouch associated with tool use.

It also is apparent that measures of curation have to be crafted for specific tool categories. We can no longer expect to use the Kuhnian index of retouch (Kuhn 1990) effectively on flake tools if they do not have scraper edges made on flakes with a triangular cross-section. The measure works very well on scrapers manufactured from flake blanks with the triangular characteristics. The point here is that curation indices need to be crafted or carefully matched to those particular tool types that are being assessed. A bifacial retouch index established for North American projectile points may not be effective for bifaces from some parts of the Old World because the two bifacial types have very different life histories. Curation is a process that is measurable, but we need to use the appropriate measures given the variety of stone tool forms with which we deal.

All the recent literature on lithic artifact and site formation processes suggests that stone tools and debitage accumulate on sites based on unique sets of circumstances that often include multiple episodes of lithic artifact production, reduction, deposition, and reuse. There should be little wonder as to why massive assemblages of lithic debitage analyzed as aggregates do not produce replicable or reliable technological information. Recent investigations such as MANA and artifact refitting studies suggest that researchers should work toward isolating these aggregate masses into their unique depositional events to better understand how such assemblages articulate with larger patterns of human land use and organizational strategies. Studies have shown that some of the most powerful technological information can be derived from a single stone tool or from a single piece of debitage. It might be best to use the most reliable information we have from a stone tool assemblage, even if it represents but a fraction of the assemblage as opposed to using a greater proportion of the assemblage to make unreliable interpretations.

Much of the recent literature in lithic studies focuses on the notion that stone tools change form and often function during their life histories. This is not something new for most lithic analysts; what is new are the ways that researchers are associating stone tool life histories with human organizational interpretations. We are becoming more sophisticated in our interpretations of stone tool form. Long gone are the notions that all stone tools fit neatly into diagnostic "traditions" or "chronological periods." This is not to say that no stone tools fit into such groupings, but to say that not all stone tools are shaped or conceived in such ways. More and more we have come to understand that lithic artifacts do not represent ancient people but instead represent the remains of a complex set of choices and activities of humans who routinely made and used stone tools. Our understanding of stone tool life histories within the context of aboriginal land-use practices has led to a better understanding of the meaning of tool forms.

There is a great deal of hope for developing a theory of lithic technological organization. We now know that lithic assemblages are created in peculiar contexts associated with human systems that have unique histories and unique sets of environmental contexts. We should not expect to see universal correlations that show mobile foragers using formalized tools and sedentary hunter-gatherers using expediently made tools (as many of us once believed). We know that tool kits are produced, used, modified, and discarded based on a more complicated set of contexts and associations. Gradually we are gaining a better understanding of how those contexts and associations are directly linked to stone tools and debitage. This is the promise and the puzzle of lithic technological organization.

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