Special Issue: Reduction Sequence, *Chaîne Opératoire*, and Other Methods: The Epistemologies of Different Approaches to Lithic Analysis

Learning From Lithics: A Perspective on the Foundation and Future of the Organization of Technology

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ABSTRACT

The history of an organization of technology approach is complicated. Rather than trace specific strands, we examine its paradigm-like nature and connections to skeptical inquiry, as well as discussing the main studies influencing our own work. An examination and modification of a classic diagram of levels of analysis in this approach, especially the addition of a consideration of the life history of lithic artifacts, facilitates application. For such application, the importance and future of experimentation, both flintknapping and simulation, are discussed. Lithic analysts are called to identify a common assemblage which we can use to test our approaches and methods.

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> *Throughout the development of behavioral research with stone tools, there is an interesting interplay of inductive and deductive reasoning, that is; between questions they ask, in the extreme: What can this stone tool tell us about behavior, and; What are the implications of behavior for stone tools?* (Magne 1985: 22)

If the date for the opening quote from Martin Magne was not provided, the language would help place it in the heyday of processual archaeology. In the 1980s, processual archaeologists were interested in developing scientific methods to reconstruct human behavior, especially following Binford's (1981) call to link the static archaeological record with dynamic behavior by building middle range theory. Since that time, processual archaeology has undergone significant critique, theory wars have waged, and today there are a number of theoretical perspectives in contemporary archaeology, including "processual plus;" in some cases, individual archaeologists adopt an eclectic theoretical perspective (Hegmon 2003). Despite these changes, we still see much of use in the processual archaeology paradigm with some modifications, such as working to minimize and make explicit bias. While it is difficult to assess the current state of theory building in archaeology to determine if this constitutes a paradigmatic crisis (*sensu* T. Kuhn 1970), there remains a sense of normal science in the general activities of archaeologists. This makes for an interesting time to consider the epistemology of our approach to lithic analysis. In exploring this topic, we found ourselves best able to describe our personal involvement with the development of an organization of technology approach (referred to here as a "TO" approach following Cobb 2000) and identify directions for future research.

Discussions of epistemology tend to simplify its meaning to how we know what we know. In this vein, Lett (1987: 11) defined epistemology as "the study of the nature and source of knowledge." However, these simplifications belie the actual complexity of explaining how we arrive at knowledge. There are numerous volumes outside of archaeology that address this philosophical issue and plenty of books and articles within the discipline that espouse one variety of knowing or another. Michael Shermer, writing outside archaeology and citing Eddington (1958), states the role of observing the observer is fulfilled by the epistemologist and that "today's observers' observers are the skeptics" (Shermer 2002: 9–10). In archaeology, Hegmon (2003: 230) suggests that "epistemological debates have been relatively uncommon in recent North American archaeology." Many archaeologists focus on the more immediate problems they see in front of them, such as excavating a site before it is

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destroyed, completing a technical report, or educating the public about the importance of archaeology, rather than engaging in deep philosophical reflections. We tend to fall into that former category as well, and our use of flintknapping experiments and developing a multiple-lines-of-evidence (MLE) method reflect this (e.g., Bradbury 1998, 2007; Bradbury and Carr 1995, 2004; Carr 1994a; Carr and Stewart 2004). Nevertheless, we do see utility in reflecting on our epistemology and in adopting the method of skepticism as espoused by Sagan (1996) and Shermer (1999, 2001, 2002, 2005).

As with the standard treatment of defining epistemology, it would be overly simplistic to identify processual archaeology as the epistemological basis for our behavioral inferences from chipped stone assemblages. This characterization glosses over which attributes we find important to record for tools and flake debris, how data are presented and analyzed, the framework we use for making inferences from those data, and so on. If we were to attempt to sum all of this into a few words, then these would be "we use an organization of technology approach." However, even this does not capture the specificity of what we do. Here, we will not write a complete history of a TO approach, and we are not evaluating contemporary studies utilizing the approach, nor are we comparing this approach with others in vogue today. Instead, we begin with the paradigm-like nature of the TO approach and examine connections to skeptical inquiry. We then more explicitly introduce the approach with a focus on the main studies influencing our own work, and summarize key elements. This is followed by examination and modification of a classic diagram of levels of TO analysis that better reflects our research design. Next, the importance and future of experimentation, both flintknapping and simulation, is discussed. We conclude with a call for lithic analysts to identify an assemblage, site, or time period that would allow for those concerned with lithics to encounter skeptics who will provide constructive criticism and move lithic analysis forward.

A LITHIC PARADIGM?

Lithic analysis can literally and figuratively be compared to putting a puzzle together. Refitting and conjoining of lithic artifacts aids in addressing a number of archaeological issues of interest from site formation processes (e.g., Villa 1982; Hofman 1986, 1992) to the sequence of flake removal in tool production (e.g., Bamforth and Becker 2000; Franklin and Simek 2008; Morrow 1996; Wyckoff 1992). The figurative analogy involves adopting an approach in the study of a lithic assemblage and piecing together a picture of the past. The same lithic assemblage can yield different pictures depending on the approach. Or, put another way, the approach an analyst chooses is based on the kind of picture that is to be pieced together.

In contemporary Americanist archaeology, there is consensus amongst *some* lithic analysts as to what that final picture should look like. That picture should involve securely identifying past technologies, determining how these technologies were organized to implement social and economic strategies, and examining the manner in which technological change is related to long-term cultural change. The lithic analyst with these goals working in North America most often implicitly or explicitly employs a TO approach (e.g., Amick 1994, 1999a; Andrefsky 1991, 1994; Bamforth 1991, 2003; Carr 1994b, 2008; Johnson and Morrow 1987; Larson 1994; Lothrop 1989; Nassaney 1996; Shott 1986, 1989).

Returning to the picture that archaeologists want to develop of the past or, more appropriately, the questions archaeologists want to answer about the past, it is evident that these derive from their paradigm. We find the use of the terms "paradigm" and "exemplar" (*sensu* T. Kuhn 1970, 1977) useful in a consideration of epistemology. Here, we follow T. Kuhn (1970: 175) in defining a paradigm as "the entire constellation of beliefs, values, techniques, and so on shared by the members of a given community." Shermer (2002: 39), in redefining paradigm, emphasizes that it is "shared by most, but not all members of a scientific community," which certainly seems to reflect the current state of archaeology. We use exemplars to mean the research that a given community uses for guidance as to proper procedures for solving research puzzles (T. Kuhn 1977: 471).

The use of the term paradigm in contemporary archaeology is often followed by discussion of processual and post-processual archaeology (e.g., Thomas and Kelly 2006: 56). We have already noted the roots of our approach, the organization of technology, are in processual archaeology. But this approach has developed such that it does not fit all the classic elements of processual archaeology. For example, instead of a strict commitment to positivism and general laws, there is the use of a scientific approach that is more akin to the modern skeptical movement. Shermer (2002: 16) suggests:

> "Modern skepticism is embodied in the scientific method, which involves gathering data to test natural explanations for natural phenomena. A claim becomes factual when it is confirmed to such an extent that it would be reasonable to offer temporary agreement. But all facts in science are provisional and subject to challenge, and therefore skepticism is a *method* leading to provisional conclusions" (emphasis in original).

Our MLE method could be said to derive from a skeptical stance taken to any one type of flake debris analysis. The use of multiple lines of evidence allows for ambiguities to be revealed in the case of disagreement or greater confidence in inferences when all lines are mutually supportive.

While not all of the "Twenty-five Fallacies That Lead Us to Believe Weird Things" are particularly relevant to archaeology (Shermer 2002: 44), archaeologists would benefit from a careful reading and reflection on skeptical thinking. Those dealing with bias are certainly relevant and bias has been noted as a concern in archaeology (Amick et al. 1989: 3; Beck and Jones 1989; Fish 1978; Odell 1989; Whittaker et al. 1998). As an example of an awareness of potential bias, Carr and Stewart (2004) recognize the difficulty of accurately identifying chert types and sought the help of regional experts to improve the accuracy of those identifications. Another example is Bamforth's (1991: 218) early work involving technological organization in which he was skeptical of a simple relationship between mobility and stone tools. He instead argues:

> "The many different combinations of environmental, social, and other circumstances in which all past human groups needed tools must have led such groups to produce different kinds of tools and to treat those tools differently. The technological adaptation followed by any human society, then, is likely to show a complex mix of strategies reflecting patterned differences in the contexts within which tools were produced and applied."

In this work, Bamforth goes on to examine a case study to demonstrate these points. He is acting the skeptic when he "questions the validity of a particular claim by calling for evidence to prove or disprove it" (Shermer 2002: 17). Pushing and pulling at existing ideas, identifying and working to minimize bias, and looking to the archaeological record for evidence through case studies are hallmarks of a TO approach.

While not strictly definitive of a paradigm, which is generally applied at a broader level, there is a scholarly community that adopts a common approach to lithic analysis. As a matter of fact, a review of "The Organization of North American Chipped Stone Tool Technologies" (Carr 1994c), an early compilation of case studies, accused the authors of having "a tight little-citing circle" (Jeske 1996: 176). This approach, then, could be described as paradigm-like because of the community of like-minded scholars, but at a different scale because it is not all-encompassing and individuals who adopt the approach may only share some of the beliefs, values, and techniques as they continue to work to more fully develop it.

We do not want to overstate the commitment of lithic analysts to any single approach, but make clear that there is great diversity concerning how best to analyze lithic assemblages. For example, Andrefsky (2007) has recently criticized the use of mass analysis for identifying the technological origin of flake debris samples. However, general trends derived from mass analysis are an important part of our MLE method (e.g., Bradbury 1998, 2006, 2007; Bradbury and Carr 2004; Carr 1994a) and the use of multiple lines of evidence is argued by Hegmon, following Wylie (1992, 1996, 2000), "to generally produce better evidential constraints" (Hegmon 2003: 231). While disavowing any connection to scientific hypothesis testing, Hodder (2005: 9) finds it "remarkable… that often the different types of data coincide so that a stronger argument can be built." With respect to lithic analysis, Magne (2001: 23) has noted that "multiple lines of evidence can be more accurate indicators of reduction realities than any single line of evidence is encouraging, since redundant measures, to a reasonable amount, can serve as internal checks to reality." While mass analysis is not without flaws, the method retains utility for providing a line of evidence for addressing the technological origin of a flake assemblage when used in conjunction with other methods of analysis. This is one of many examples that could be used to demonstrate the diversity of lithic methods in use by North American archaeologists, both under and outside the umbrella of a TO approach.

In another case drawn more explicitly from a TO approach and at a more abstract level, some researchers have found general utility in using the concept of curation to link rather directly to aspects of human behavior such as logistical mobility (*sensu* Binford 1980). This straightforward connection may not always hold. For example, it has been argued that both collectors and foragers would use curated tools under certain conditions (Carr 1994a). Further, the utility of the concept of curation has been questioned (e.g., Bamforth 1986; Nash 1996, Shott 1996). Different facets of the concept have been identified, such that curation is recognized to include production in advance of use, design for multiple use, transport from location to location, recycling, and maintenance, which makes it critical to precisely define specific usage (Odell 1996). In another attempt to do away with ambiguity, Shott (1989, 1996) has precisely defined curation as the amount of use obtained from a tool compared to the potential utility of that tool. While it is apparent the concept of curation is central to a TO approach, the lack of consensus in its usage is problematic. It does demonstrate the need and potential for further development and refinement.

These examples illustrate the dynamic state of lithic analysis and that a TO approach is not static, rather methodological and theoretical advancements continue to be made. This is exemplified by Cobb (2000) in his examination of Mississippian hoe production where he critiques the traditional TO approach and begins building one with a greater focus on labor and the social construction of technology. Cobb's work is an excellent example of what Hegmon (2003) calls "processual plus" as demonstrated by his focus on agency and the importance of gender. Whether this dynamism is a sign of a scientific crisis to come, or simply the development and articulation of an approach that will have some longevity, is unclear. Our sense, as with Cobb (2000: 97), is that the basics of organization of technology studies will remain even as other more general considerations change and specific methodologies are further developed.

The development of a TO approach has its roots as far back as the 1960s, and arguably the 1890s. However, the strong coalescence of various ideas and the identification of something called "organization of technology" in lithic analysis occurred in the mid to late 1980s. Our training in lithic analysis was most intense at this time such that we entered the specialization and "grew up" with TO while being exposed to various other paradigms and approaches. We have continued to try to interpret specific lithic assemblages, but also heed the criticisms of the methods and approach we use. In conducting case studies and continuing to engage in discussions of theory, we see continued utility in the use of this approach. By working to explicitly define key elements and applying it in case studies, a TO approach can provide provisional conclusions, while also remaining open to scrutiny.

OUR FOUNDATION IN THE ORGANIZATION OF TECHNOLOGY

Twenty-five years ago was an exciting time to be studying lithic assemblages. High-level theoretical debates were waging, but some lithic analysts were avoiding the fray to work on combining tool life history with behavioral concerns. Stone tools were seen as holding much more information than culture history alone and the limits on behavioral inferences were bounded by techniques and not inherent to the artifact class. Further, there was heightened recognition that variability in the entire lithic assemblage, not just formal tools, could provide information about human behavior. In particular, flake debris analysis was burgeoning in the mid-1980s. Finally, it was realized that experimentation was not only critical for determining stone tool manufacture methods and use, as was so important in the 1960s and 70s, but also for providing a means to gain other behavioral information from lithic assemblages. Controlled flintknapping experiments were employed to determine the efficacy of various flake attributes for assigning stages of reduction (e.g., Magne 1985) or characterizing an assemblage (e.g., Ahler 1975). Coalescence of these various strands of archaeological method and theory did not produce what could be described as a single, unified approach, but perhaps is better described as inspiring a variety of studies with similar intents. Therefore, we will discuss a limited, and admittedly biased, set of exemplars of TO studies that have had the greatest impact on our work.

Our title "Learning from Lithics" in some ways parallels "Lithics and Livelihood" (Magne 1985) an important exemplar for modern North American lithic studies utilizing a TO approach as its impact reached far south of the Canadian-U.S. border. Our reading of this study has not produced the use of the phrases "technological organization" or "organization of technology," but discussions of technological strategies, curation, and maintenance, clearly show the underpinnings of a TO approach. The importance of the theoretical and ethnographic work of Lewis Binford (e.g., 1977, 1978, 1979, 1980, 1982) is clearly evident in Magne's study and has remained consequential for contemporary lithic analysts and his students were instrumental in further developing this approach (i.e., Amick 1994, 1999a; Ingbar 1994; Kelly 1988, 1994; S. Kuhn 1989). Magne (1985: 251) took what he described as a "general model of the operations of lithic technologies…" from Collins (1975), also known as a life-history framework (others also worked in a similar manner around the same time, e.g., Bradley 1975; Schiffer 1976; Sheets 1975), and combined it with experimental work. This experimental work was aimed at providing accurate inferences of the stages of manufacture represented by flake debris, in order to use a behavioral perspective "that assumes the major conditioners of assemblage variations are human activities." He was able to draw a number of conclusions from his study of archaeological assemblages from British Columbia, but a key was that "site occupation purposes… can be reliably predicted on the basis of tool and debitage co-associations" (Magne 1985: 257–258). Of importance for us in Magne's study is that he explicitly linked the archaeological record with behavior—providing the opportunity for scrutiny and discussion.

While his predictions could not be easily transferred to other regions, he demonstrated that there was more to learn from lithics other than simple counts of this artifact type or that attribute state. In addition, he assessed what flake attributes provided the most reliable information concerning reduction stage and explicitly defined his categories. This moved beyond traditional flake analysis and showed how well conducted experiments could be used to address archaeological problems. These parts of Magne's work provided stimulus for our own experimental work (e.g., Bradbury and Carr 1995, 1999, 2004; Carr and Bradbury 2001, 2004) that built on the work that he and others (e.g., Ahler 1989a, 1989b; papers in Amick and Mauldin 1989), had accomplished in lithic analysis and is further discussed here in a subsequent section.

The lithic technology model that was one key to Magne's (1985) work and has continued to be an important part of the foundation of TO studies is a rather simple flowchart. Magne (1985: 23) points out that such a model "was roughly developed by Holmes (1890) and has been refined by several researchers" and he focuses on a revised version developed by Collins (1975). The common version of this flowchart used in TO studies today is as follows: raw material acquisition, tool manufacture, use, maintenance/reuse, and discard. This type of "life-history framework" is considered a core concept of Behavioral Archaeology and "now employed by virtually all serious students of technology" (Schiffer et al. 2001). It is woven in the definition of the organization of technology provided by Nelson (1991: 57) and cited by others (e.g., Carr 1994c: 1):

> "the study of the selection and integration of strategies for making, using, transporting, and discarding tools and the materials needed for their manufacture and maintenance. Studies of the organization of technology consider economic and social variables that influence those strategies."

This has helped keep the focus of TO studies on behavior or, following Magne (1985: 22), a focus on the question: "What are the implications of behavior for stone tools?"

One example of this approach is Robert Kelly's (1988) now classic "Three Sides of a Biface" article, which not only demonstrates his sense of humor, but also provides a major impetus for TO studies—investigation of mobility patterns. Kelly (1988: 717) states "Three different sorts of bifacial tools - by-products of the shaping process, cores, and long use-life tools - are used to consider the role mobility plays in producing variability in hunter-gatherer lithic technologies." A change in mobility pattern is inferred in the prehistoric occupation of the raw-material poor Carson Sink as evidenced by a change in the stone tool assemblages from bifaces as cores to the less-common bifaces as tools. A number of case studies focused on mobility and working with concepts derived from the TO approach followed this seminal work (see chapters in Carr 1994b; also Amick 1999b).

One influence of "three sides" on our own work was the linkage of stone assemblages with mobility patterns and the importance of recognizing raw material distributions as a linchpin to such studies. For Carr (1994: 36), it was that "hunter-gatherers employing different mobility strategies (in the same environment) would likely organize their technologies differently." Also, the potential importance of bifacial cores was noted and there was a call for experimentation to determine if flakes produced from bifacial cores would be classified as early stage in the scheme employed (Carr 1994a: 42). That bifaces could serve multiple purposes was also an important lesson from "three sides," and indicated the necessity of a more thorough examination of these implements to understand in prehistoric societies. Micro-wear analysis in conjunction with a technological study of bifaces allows one to determine whether bifaces represent a stage in the reduction sequence (e.g., Bradbury 1998) or formal tools used in various activities that were part of a curated technology (e.g., Bradbury 2006).

While it was recognized in the early 1990s that TO studies to that point were narrowly focused on mobility (part of the legacy of "three sides"), it was argued that mobility was a behavior that had tremendous implications for stone tools and deserved consideration along with other factors (Carr 1994c: 2–3). Despite this argument, the case study approach and focus on mobility were criticized (Simek 1994; Torrence 1994). These criticisms did not negate the importance of mobility or the usefulness of making inferences about prehistoric behavior, but rightly suggested that the TO approach needed expansion and refinement. With this, we whole-heartedly agree, and see these deriving not only from the breadth of the questions asked, but also from application to specific assemblages and determining what works and what does not. By so doing, not only is the approach refined, but new areas for productive expansion are identified.

Elsewhere, Close (2006: 1–6) has criticized American lithic analysts for placing too much emphasis on bifaces to the exclusion of other lithic artifacts and perhaps "three sides" is partially to blame. To an outsider, unfamiliar with the literature, such a criticism might appear valid. However, discussions of non-bifacial tools and cores are common. An entire volume was devoted to the examination of cores using a TO approach (Johnson and Morrow 1987). Clovis blades, though certainly not ubiquitous on Paleoindian sites, have been discussed in detail (e.g., Collins 1999) and Parry (1994) has compared and contrasted blade technologies in North America using a TO approach. Early flintknapping experiments (e.g., Ahler 1975; Magne 1985) included a variety of tool and core forms and this tradition continues (e.g., Bradbury and Carr 1995; Carr and Bradbury 2004). In an examination of stone tools and mobility, Odell (1994, 1996) integrates bifacial and non-bifacial tools to examine Early Archaic through Mississippian use of the Illinois Valley. Further, Adams (2002) provides a thorough discussion of ground stone tools from using a TO approach. A lengthier list could be compiled, but these examples should suffice to demonstrate the variety of analyses conducted using a TO approach.

From our own work we note that, in many cases, bifaces are the dominant non-flake item recovered. For example, on a short-term, residential, Early Archaic site in Lawrence County, Kentucky, of the 43 chipped stone implements, 42 were bifaces and one was a retouched flake (Bradbury 2007). Three cores and flake debris were also part of the assemblage. One can only study what is recovered from a site.

Returning to Kelly's (1988) original piece, in true skeptical fashion, Prasciunas (2007) examined the oft cited statement that bifacial cores are more efficient than amorphous cores for producing flakes. She reports the results of two different experiments to test the validity of this statement. The first established a size threshold for flake cutting efficiency and the second used that threshold to calculate whether amorphous cores or bifacial cores more efficiently produced flakes of the predetermined size. Prasciunas (2007: 341) found that "bifacial cores produce more usable flake edge than amorphous cores only when very small flakes are included in the analysis… The results of the cutting experiment suggest that flakes of this size are not useful as tools… Bifacial cores never produce more total flake edge than amorphous cores." The implication from this is that "mobile populations must have had reasons other than flake production efficiency for using bifacial cores" and these are further explored in her work (Prasciunas 2007: 345).

This is an excellent study; and it is the start of the investigation of bifacial and amorphous cores, not the conclusion. While we find this study intriguing, it also sets off our skeptical radar for several reasons. Our concern is that the flake efficiency experiment was limited to cutting and was conducted by a single individual. What other tasks might small flakes produced from bifacial cores prove useful and would other individual cutters find the same size threshold? Additionally, could these small flakes be hafted in a simple manner and provide usable edges? One flintknapper produced the flakes from one raw material. How does knapper knowledge (not just skill) impact the study? What parameters were given for the production of a bifacial core to start and how did raw material affect this? These questions are not meant as criticisms of this important study which has moved our understanding of bifacial cores forward, but rather as providing constructive avenues for future research.

One fruitful avenue of future work with bifacial cores would be to explicitly examine an archaeological assemblage in light of these experimental results and conduct new experiments. It has been effectively argued by Amick et al. (1989: 8) that "[t]he ability to work back and forth between experimental work and the archaeological record is essential for learning about the past." By detailed examination of bifacial cores and use-wear analysis to determine the size and function of utilized flakes in a particular archaeological assemblage, new information will be available to conduct additional experiments that more closely model that archaeological assemblage. In order for us to offer "temporary agreement" of the provisional conclusion that amorphous cores are more efficient than bifacial cores of producing usable flake edge, additional studies are necessary. The lack of such studies does not detract from the excellent, initial work of Prasciunas in this area. The limited number of knappers and lithic analysts conducting such experimental work suggests to us that these additional studies are unlikely to occur in the near future. For example, Kelly (1994: 135) called for a workshop/conference bringing together those interested in technological organization and expert flintknappers "to hold experiments and seriously evaluate things." To our knowledge, no such workshop/conference has been held.

Another seminal study that helped provide some of the language for examining a key element of TO studies, tool design, was conducted by Peter Bleed (1986) on reliable and maintainable designs. Like Kelly's (1988) discussion of bifaces, these concepts helped focus lithic analysis on the implications of behavior for stone tools. Previously, Binford (1977, 1979) provided a discussion of curated and expedient technological strategies. These technological strategies and design concepts were more formally united in a diagram of a TO approach by Nelson (1991), which receives considerable attention in the following section.

While the concept of curation has been criticized and it has been demonstrated that it is only as useful as the definition provided, it is accurate to say that the initial discussion of curated and expedient technological strategies were important components in developing a TO approach. The original sense of these terms, while often discussed, is worth repeating here. Expedient tools are those that are manufactured, used, and discarded at the same location. Unretouched flakes (i.e., utilized flakes) produced from amorphous cores are often used as evidence of an expedient technological strategy in an archaeological assemblage. Curated tools are those for which the location of manufacture, use, and discard are different. It is recognized that curated tools form a continuum from those that are part of a toolkit for only a short period of time, perhaps a day, to those that may be in a toolkit for years. For example, a projectile point may be manufactured during gearing up activities, and then used during a hunting foray. If broken, the tip of the tool may enter the archaeological record the same day and the remainder during the next retooling session. Ground stone axes, in contrast, would be expected to remain in a toolkit for an extended period of time, perhaps measured in years rather than days. In an effort to make clear that expediency is a planned technological strategy, Nelson (1991) provides a discussion of opportunistic technological behavior, which is not planned.

Bleed's (1986) work on design makes use of Binford's discussion of technology and mobility, especially his description of foragers and collectors (Binford 1980). Bleed (1986: 737) presents the case that "archaeologists can link the design of prehistoric weapons to environmental constraints and to specific hunting strategies." He discusses two design alternatives for maximizing the availability of a technical system—reliable and maintainable. A reliable tool is one that is dependable so that it will work when needed, and reliable systems characteristics include overdesigned components, parallel subsystems and components, and carefully fitted parts/generally good craftsmanship (Bleed 1986: Table 1). In contrast, maintainable tools can be "quickly and easily brought to a functional state" even if broken or not designed for the task at hand (Bleed 1986: 739). The characteristics of maintainable systems include generally light and portable, modular design, and repair and maintenance occur during use (Bleed 1986: Table 1). Reliable designs are optimal when failure costs are high or when tasks have predictable schedules with available down time. Maintainable tools are best for generalized tasks where there is a continuous need but unpredictable schedules and failure costs are low. Bleed (1986: 741) explicitly links maintainable hunting weapons with foragers and reliable hunting weapons with collectors. This was important, not because it allows for a simplistic connection between tool design and mobility patterns, but because it broke the pre-existing equation of foragers with expedient tools and collectors with curated tools. Expedient tools are manufactured with little or no design considerations, meaning reliable and maintainable designs are considerations for curated tools. It follows that foragers and collectors would both use expedient and curated tools depending on a number of factors, including raw material availability (Carr 1994a).

In a more recent expansion on this early work on technological design, Bamforth and Bleed (1997: 116) argue that "the logic of virtually all of the theoretical literature on flaked stone technology…rests on the assumption that the central problem that technological strategies have to solve is that of ensuring that the tools on which humans rely are available and in useful condition when they are needed." It is the concept of risk, they argue, that can provide an overarching framework for the study of material culture generally and chipped-stone assemblages particularly. In this framework, they incorporate some aspects of design from Bleed's (1986) earlier work in discussing options for averting risk of failure in three domains—procurement (designing long use-life tools and designing multi-function tools), production (reliance on technologically simple tools), and application (careful design for specific purposes, overdesign to prevent breakage, and design for easy repair) (Bamforth and Bleed 1997: 128). Like other lithic analysts using a TO approach, we have not explicitly incorporated risk in our study of prehistoric chipped stone assemblages, but do see utility in the framework provided here and more explicitly considering technology and design in a "risk aversion" framework (e.g., Torrence 1989).

Design theory does have its detractors, especially with regard to utilizing concepts such maintainable and reliable. Odell suggests that while originally holding promise that the reality is "all tools are both reliable and maintainable…

expressing these qualities precisely is very difficult... quantifying them for comparison is even more difficult" (Odell 2001: 79). Granting these difficulties, these concepts have played an important role in shaping the way archaeologists think about stone tools and, in turn, the possibility for overcoming these difficulties exists. Odell recognizes that "an approach to assemblage variability that incorporated these concepts might bring the analyst closer to understanding the way specific tool types functioned within the rubric of prehistoric society than by pursuing more traditional artifact analyses" (Odell 2003: 191).

KEY ELEMENTS OF A TO APPROACH

From this discussion, a number of central concepts of a TO approach (paradigm) have been identified, which include: lithic assemblages and stone tool technologies can provide information about human behavior; the entire lithic assemblage is necessary to effectively make inferences; knowledge of raw material distributions and accurate identifications in the archaeological assemblage are essential to this end; tool life history provides a useful framework for conduct of the analysis; and, experimentation is necessary for linking dynamic behavior to the static archaeological record. Despite criticisms, investigation of mobility remains a key concern (e.g., Brantingham 2006; Ingbar and Hofman 1999; Kornfeld 2002; Odell 2001; Prasciunas 2007; Thacker 2006), but agency, gender, labor, risk social alliances, and trade are included in some studies (e.g., Amick 1999b; Bamforth and Bleed 1997; Carr and Stewart 2004; Cobb 2000; Sassaman 1994) and should receive increasing consideration in the future. While not explicitly part of the traditional TO approach, inspiration from the modern skeptic movement has the potential to aid archaeologists in their investigations of lithic assemblages.

CONTINUING TO BUILD AN ORGANIZATION OF TECHNOLOGY APPROACH

In addition to providing a definition of the organization of technology, Nelson (1991: 59) develops a diagram of the "Levels of analysis in research on technological organization" (Figure 1). It is said that a picture is worth a thousand words. For us, this diagram illustrating TO was priceless as it provided the framework through which we thought about lithic assemblages by helping to make sense of the various contributors to the TO approach. The levels of analysis that linked the "holy grail" of processual studies, social and economic strategies, to lithic assemblages, with the recognition that each unique environmental setting would engender different strategies was what provided the clarity we needed to conduct meaningful lithic studies. Without this and other exemplars, we would just as likely have been criticized along with other lithic analysts for "chasing rainbows" (Thomas 1986: 247). However, there are difficulties in applying this diagram, especially with finding a means to integrate data from flake debris. While finding Nelson's diagram of much use, we modified it slightly to make explicit certain connections and provide detail to augment application.

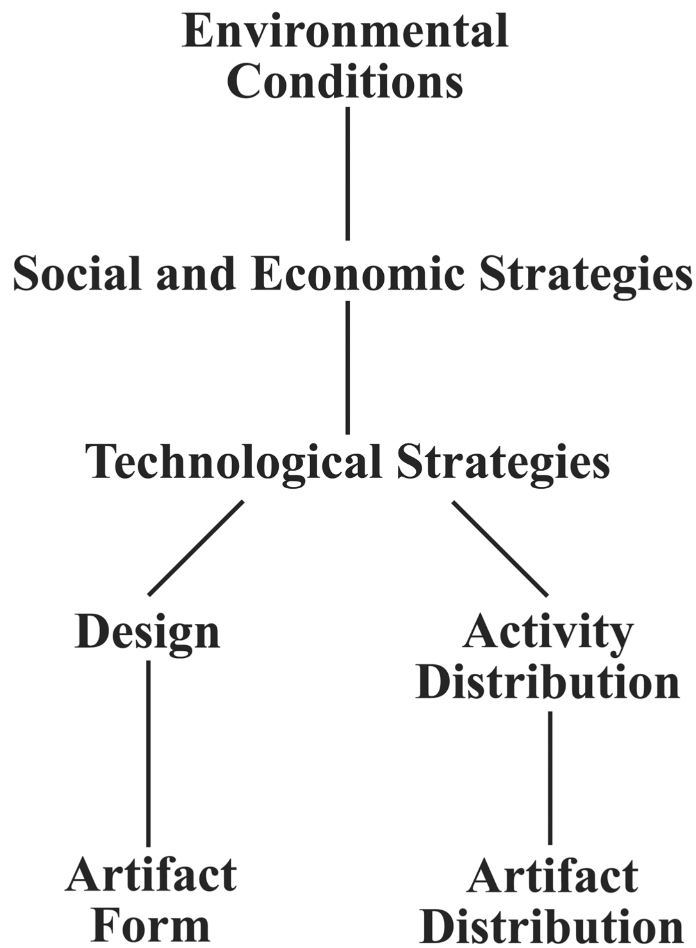

Figure 1. Framework for conducting TO studies (after Nelson 1991:59).

In the original diagram, the Environment is at the head as the context in which everything is played out; the arena in which technology needs to be effective and responsive. Economic and Social Strategies are employed by prehistoric peoples within an Environment and their technology fulfills the demands of these strategies. As part of social and economic strategies, kinship, politics, and religion can all affect technology as does subsistence and settlement patterns. Economic and Social Strategies together affect both Design and Activity Distribution through Technological Strategies. That is, depending on the Environment and the Economic and Social Strategies employed, different aspects of Design will be emphasized by prehistoric peoples. Traditionally, this involves whether the Technological Strategy is expedient or curated, though Nelson (1991: 62) adds opportunistic, and further whether curated tools are designed to be maintainable or reliable. In terms of Activity Distribution, mobility patterns, as an aspect of Economic and Social Strategies, will affect where different activities will occur as well as the Technological Strategy employed. These in turn influence Artifact Distribution. The final piece of the diagram is that Design impacts Artifact Form. For example, a reliable tool will have different observable characteristics than one designed to be maintainable.

Nelson (1991: 62–77) focuses attention on the relationship of Technological Strategies (expedient, curated) to Design (reliability, maintainability, versatility, flexibility, transportability). As discussed, curation is a strategy that has since received significant attention (e.g., Odell 1996; Nash 1996; Shott 1989, 1996), but design concepts are less-well developed in chipped-stone studies. Perhaps lithic analysts can draw more broadly on design as discussed for other material culture (e.g., McGuire and Schiffer 1983; Schiffer and Skibo 1987, 1997). Nelson (1991: 77–87) also discusses Artifact Distribution, mainly in terms of making site function inferences. She is critical of a site-type approach and points out the complexity and variability of technological strategies, settlement patterns, and site formation processes (Nelson 1991: 84–85). However, Technological Strategies as a level of analysis needs consideration more broadly than simply refining the meaning of curation. We argue that continued examination of specific aspects of this diagram and the relationship of the various components can aid in advancing our understanding of lithic assemblage variability.

While helping to guide our own research, there is a need to more explicitly focus on entire lithic assemblages (i.e., flakes, cores, tools) rather than just parts of the assemblage (e.g., formal flaked tools) and to further explore certain elements of this TO diagram. We offer a modified version here (Figure 2). In the modified diagram, "Activity Distribution" is simplified to "Activities" and it is emphasized that Design and Activities affect *both* Artifact Form and Artifact Distribution, as well as each other. That is, lithic assemblage composition is a result of both Design and Activities. In our modified diagram, the Activities shown are those that pertain specifically to tool life history, but we recognize that many other activities result from Economic and Social Strategies. However, it is important to minimally and explicitly consider the Activities shown when employing a TO approach. For example, the acquisition of raw materials not only impacts the distribution of artifacts, but also the forms those artifacts will take. The acquisition of locally available, small, quartz cobbles as opposed to large nodules of high-quality, non-local chert will affect Artifact Form. Consider further how Artifact Form is responsive to Activities because of the impact of use and reuse. Artifact Form includes breakage patterns resulting from use activities and resharpening from tool maintenance certainly affects form. It is also easily seen how Design not only impacts Artifact Form, but also Artifact Distribution or, more generally, lithic assemblage composition. If expedient flakes are the tools of choice, the resultant flake debris and cores would significantly differ from an assemblage resulting from the design of bifacial tools as curated, long use-life tools.

The TO diagram also was modified such that there is an explicit relationship between Design and Activities. Tool design is responsive to the activities conducted and the location of those activities. Consider the case of a highly mobile group who values high quality tool stone for the manufacture of reliable tools. The necessity to design reliable tools is derived from the demands of Economic and Social Strategies as implemented through Technological Strategies. In this case, the group will engage in the Activity of high quality raw material acquisition in order to meet the Design requirements of reliable tools. Interestingly, the acquisition of high quality raw materials may require adjustments in Economic and Social Strategies or place new demands on these strategies. That is, trade between various members of the larger social group during periods of aggregation or procurement of tool stone during hunting forays. As noted by Torrence (1989: 64) "raw materials and manufacturing strategies are the result of careful choices made within the wider context of the tool-using behavior, which in turn is a solution to a particular problem." We also note that cultural factors may come into play. For example, Knecht (1997: 207) cites McGhee's study of the Thule in which sea mammals were hunted with materials obtained from the sea while land mammals were hunted with media obtained from the land. In this case, raw material selection (for projectile points) was based largely on cultural factors. As discussed previously, a TO approach is in something of a state of becoming, and while our modifications to Nelson's diagram help focus attention on areas we find of interest, further changes will undoubtedly help capture more of the complexity that patterns lithic assemblages. For example, Technological Strategies requires new attention and expansion beyond curated, expedient, and opportunistic, and remains a future challenge.

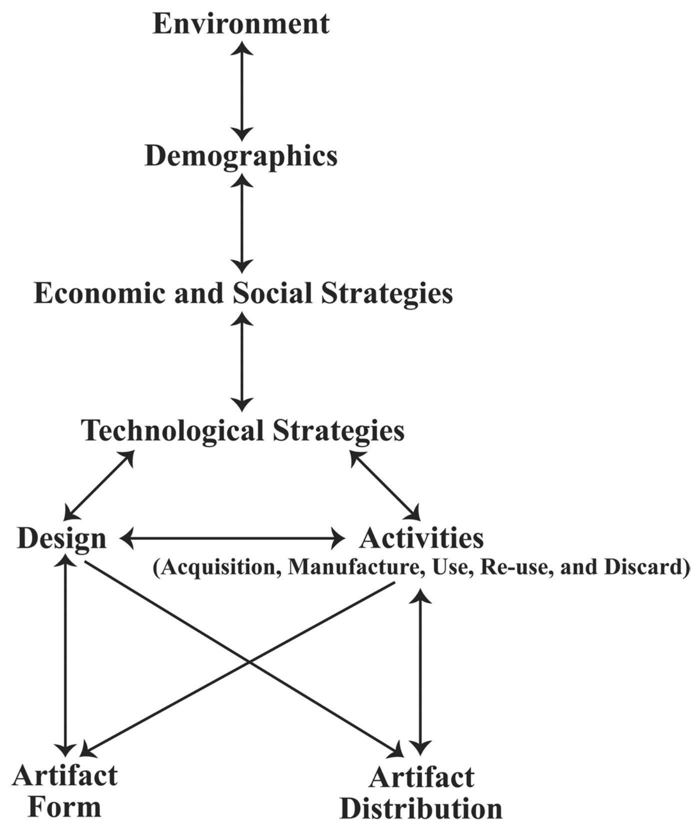

Figure 2. Modified framework for conducting TO studies (after Nelson 1991: 59).

MODERN EXPERIMENT AND PREHISTORIC BEHAVIOR

We now turn attention to another aspect of Magne's (1985) work that makes it an exemplar of TO studies—flintknapping experimentation to aid in understanding lithic assemblage variability, particularly flake debris. Researchers conducting studies of technological organization have understood that flakes are an important complement to stone tool analysis and that flakes are particularly useful in broadening the kinds of answers one gets when asking "what can lithic assemblages tell us about behavior" (Magne 1985: 22). Two published volumes, *Lithic Debitage: Context, Form, and Meaning* (Andrefsky 2001a) and *Aggregate Analysis in Chipped Stone* (Hall and Larson 2004), are testament to the fact that flake debris analysis is an integral part of American lithic studies. Further, the importance of flintknapping experimentation as a means to understand flake debris variability is also apparent as it plays a key role in the majority of those studies.

Ironically, it can be argued that the Sullivan and Rozen (1985) flake debris classification system, which is not based on experimentation, is what prompted the conduct of a variety of flintknapping experiments in the mid to late 1980's aimed at better understanding flake attributes, their relationship to manufacture, and how to best classify flake debris. Many of the papers in the classic edited volume entitled *Experiments in Lithic Technology* (Amick and Mauldin1989) explicitly set out to test whether percentages of certain flake types (complete flakes, broken flakes, flake fragments, split flakes, and debris) could be used to make inferences concerning tool production versus core reduction.

In Americanist lithic studies, there are currently two main approaches to the study of flake debris—aggregate analysis and individual flake analysis. Ahler (1975, 1989a, 1989b) has long been a proponent of aggregate-based flake-debris analysis. In short, his mass analysis (a specific type of aggregate analysis) focuses on size, shape, and cortex characteristics of batches of flake debris as a means of measuring and quantifying variation within the assemblage. Ahler (1989b: 89) discusses two general observations regarding flintknapping which are relevant to mass analysis: 1) flintknapping is a reductive technology; therefore, there are predictable and repetitive size constraints on the byproducts; and, 2) variation in load application (e.g., percussor used, placement of load) in the flintknapping procedure produces corresponding variations in flake size and shape. In contrast to aggregate analysis, individual-flake analysis relies on recording specific attributes of a single flake to assign it to core reduction or tool production, to assign it to a stage (e.g., Magne 1985), or to place it on a continuum (e.g. Bradbury and Carr 1999; Ingbar et al. 1989; Shott 1996). These attributes include completeness, platform-facet count, dorsal scar-count, and so on. There is no consensus concerning which is the best method and, as previously stated, it depends to some degree on the kind of picture you want to develop for the past, as well as constraints of time and money. Andrefsky (2001b: 13) sums it up as "There is no ultimate kind or level of debitage analysis…there is no magic technique… Instead, it is apparent that different techniques will provide different kinds of information about the overall site assemblage."

Recently, Andrefsky (2007) criticized one form of aggregate flake debris analysis (mass analysis). While we are in agreement that relying on untrained people performing the work (or using mechanical shakers to size grade flakes) is unacceptable and will not produce reliable results, we have several basic issues with his critique. Given that mass analysis is a multivariate technique, it is inappropriate to use univariate statistics and simple histograms to argue against its utility as Andrefsky has done. His sample sizes appear too small to test for variability among different knappers and this is also a problem for examining other aspects of the method. There are inconsistencies in application of mass analysis in the various cited experimental assemblages used to demonstrate problems with the method and failure to control for raw material differences between these assemblages. It appears that more experimental work is needed before we fully understand the utility and limitations of mass analysis.

We have shown through experimentation the utility of combining aggregate analysis and individual-flake analysis in order to employ the MLE method. Due to the complexity of flake assemblage formation, including both natural and cultural factors, we are not ready to say that any specific method of flake debris analysis based on flintknapping experimentation can have world-wide utility, representing the proverbial "silver bullet." However, if there is a convergence of multiple lines of evidence regarding the formation of a lithic assemblage, then some confidence can be shown in the inferred processes (Bradbury 1998, 2006, 2007; Carr 1994a, Carr and Stewart 2004).

As an example of this type of approach, one of us analyzed flake debris from an Early Archaic site (15CU31) in south central Kentucky (Bradbury 1998). Three methods of flake debris analysis were employed in this examination (a continuum approach, mass analysis, and individual flake analysis). Consideration of the flake debris was critical for site interpretation since few implements were recovered. Results of the disparate methods of flake analysis converged—indicating an emphasis on tool production and, more specifically, early to middle stages of biface production focusing on one of the local cherts—resulting in a higher degree of confidence in this interpretation. The inferred manufacture activities were then used in conjunction with tool and core analyses to provide further inferences of prehistoric behavior. Namely, lithic materials arrived at the site as partially roughed out bifaces, were further reduced on site, and transported elsewhere for additional reduction and use. Technological and micro-wear analyses of the recovered bifaces indicated that almost all broke during manufacture (and before use), which further demonstrates that biface production was the main site activity.

An early study that exemplifies the use of lithic assemblage variability that has received far too little attention is Magne's (1989) use of lithic reduction stages and tool data to infer aspects of behavior. In this study, two models are developed—one involves the formation of lithic assemblages based on the percent of late stage debitage graphed by a debitage/tool ratio and the other graphs percent late stage debitage by tool diversity slope to infer site type. Magne's first model, lithic assemblage formation, links an increase in tool maintenance activities with an increase in the percent of late stage flake debitage. If there was a high discard rate of tools, then the debitage to tool ratio would be low in this situation (low tool conservation rate). However, if there was a low tool discard rate and a high conservation rate then the debitage/tool ratio will be high. On the other hand, if the focus is on tool manufacture, then there is a low percent of late stage debitage. If the debitage/tool ratio is also low, then there is a high rejection rate of tools, but if it is high, then there is a high export rate. The second model, site type, also has four basic outcomes (residences, repeated logistical camps, manufacturing sites, and situational 'emergency' camps). While the use of "site types" has been criticized by a number of authors (e.g., Bettinger 1979; Dunnell 1992; Nelson 1991), we find that Magne's model serves as a heuristic device that makes explicit connections between patterning in lithic assemblages and human behavior. Too often an inference is made concerning site function or site type with only vague references to the evidence for such inference. Additionally, application of such models is often difficult in specific cases due to site formation processes. Larson (2004: 14–17) has effectively argued the importance of partitioning lithic assemblages into meaningful samples for analysis and understanding the context of those samples. For example, application of a model to the entire lithic assemblage from a multicomponent palimpsest will not produce useful results. This problem of "time-averaging" with regard to lithic assemblages "may eradicate the fine details" needed to apply a TO approach (Brantingham 2003: 504).

Given that technological organization is further developed since the original publication of Magne's models (1989: Figures 1 and 7), we would recommend looking at the revised framework for conducting TO studies presented here and refining the models developed by Magne and producing new ones. In particular, we would argue that the environment, particularly the distribution of raw materials, will impact these types of models (Andrefsky 1994; Carr 1994a). Additionally, we suggest simulation as a fruitful avenue for future research in this regard. Recent archaeological simulations include application in a wide array of areas from early hominid behavior (Goodhall et al. 2002; Mithen and Reed 2002) to prehistoric settlement systems in the North American Southwest (Dean et al. 1999; Kohler et al. 2000). Ingbar (1994) effectively combined a TO approach and simulation for investigating lithic raw material distributions. One important conclusion derived from his simple simulations is that raw material presence in an assemblage likely represents the minimum extent of a group's range (Ingbar 1994). We are currently working to build on Ingbar's work in terms of simulating toolkit composition and lithic assemblage formation for the Early Archaic in the Southeast U.S.

Why simulate? Simulation can serve as something of a proxy for ethnographic cultures in that it allows us to think about the parameters that underlie the formation of the archaeological record, but also may be truer to that archaeological record in the sense that specific conditions experienced by prehistoric peoples can be modeled. That is, environmental factors such as raw material distributions, waterways as travel routes, and available food resources, as known from archaeological data, are the foundation of the simulation model. We envision a detailed prehistoric landscape for our stone tool making and using simulated people to inhabit. An important advantage of simulation is that it provides the opportunity to modify certain parameters, while keeping others constant. In this way, we can get an understanding of the effect of a single variable. For example, we can increase the stay at a residential base and see how this might effect what is discarded into the archaeological record. This is likely to impact both the amount of lithic materials and the diversity. Once you have explored a variety of simulations, the results are matched against archaeological data and a variety of questions asked. Are the results comparable? If not, where do the discrepancies lie? This allows one to refine the model in a feedback loop that involves the archaeological record that you are attempting to explain. Further, predictions based on the simulation of what should be found at specific locales and site types could be tested with new archaeological data to assess the efficacy of the model.

Interestingly, a simple simulation conducted by Brantingham (2003) calls into question the utility of a TO approach, especially with regard to making inferences from raw material data. Data from his "neutral" model of stone raw material procurement and discard suggest that "Paleolithic behavioral adaptations were sometimes not responsive to differences between stone raw material types in the ways implied by current archaeological theory" (Brantingham 2003: 487). This model provides much food for thought, but in some cases we are learning more about the rules of the simulation than prehistoric behavior. While the author is aware of a number of potential criticisms, areas we see that deserve particular attention include the number of unique raw material sources, the necessity of maintaining a toolkit of constant size but allowing that toolkit to reach zero at times, and failure to consider tool form. The current parameters used in the model in these regards make any conclusions drawn from it suspect.

The future of simulation in archaeological studies, especially lithic studies, appears quite promising, whether the simulation provides a neutral model or specific landscape case study of stone tool assemblage formation. Such models generally require significant time to develop because of the thought and computer programming demanded. Fruitful collaborations could spawn from a workshop attended by programmers and lithic specialists in something of the same vein as suggested by Kelly for flintknappers and those using an organization of technology paradigm.

SUMMARY AND CONCLUSIONS

Here, we have briefly explored what we think can be learned from lithics in an admittedly brief and biased review of the literature. Many important studies that contributed to the formation of a TO approach were not discussed, but some lessons were learned from those that were considered. First, more explicitly combining a tool life-history model into Nelson's framework for conducting TO studies may lead to a deeper understanding of lithic assemblage formation and aid in answering the question, "what are the implications of behavior for stone tools?" Second, there is not a single dominant method or suite of methods employed by all lithic analysts, nor do we advocate that there necessarily needs to be one. Methods should be chosen based on a variety of factors including the kind of picture that is hoped to be developed about the past, the skill of the analyst, and the time available to conduct an analysis. In any case, we would recommend employing multiple methods when analyzing any assemblage to serve as a system of checks and balances. To aid in inter-site comparisons, a minimum set of attributes that is recorded in all studies as suggested by Shott (1994) still has merit. Insuring the validity of such comparisons may not be easy due to inter-observer error, but the goal is worthy and necessary if we are to gain a fuller picture of the past.

We would also argue for more flintknapping experimentation to aid in answering the question, "what can this stone tool tell us about behavior?" Such experiments could be used to further assess methods already in use, redefine such methods, or develop new ones. An increase in the numbers of knappers and the raw materials examined would aid in assessing the applicability of results. For example, are there potential biases that may be related to variation in raw material or knapper? Further, the development of more sophisticated models involving lithic assemblage formation, particularly simulation models, can serve as an important means for continuing to integrate a TO approach and flintknapping experimentation. That is, if you are building a simulation there are many questions that need to be answered and many can be addressed through experimentation. How many flakes are produced when resharpening a biface? How often does a biface need to be resharpened? A working simulation will be a mammoth undertaking, but well worth the effort, because benefits will come from the construction as new avenues of method and theory are explored.

One final point we would like to make is that at least some of the impetus for developing a TO approach was the Binford-Bordes Debate concerning the Mousterian Problem. The focus on this one issue helped drive lithic analysis forward. Various researchers employing disparate approaches could examine the Mousterian problem from their perspective. Since everyone was so familiar with this problem, the result of looking at it from a new perspective was even more readily apparent. That is, drawing new conclusions about the Mousterian Problem using a new method made its relevancy more apparent and available to a wider audience than if that new method had been applied to a site in the Southeast U.S. We would suggest that the adoption of a "site" or number of sites to serve as study exemplars might serve the same role as the Mousterian Problem did for so many years. For American lithic analysts, a Paleoindian assemblage might have the flare to capture the interest of various analysts and serve as something of a penultimate exemplar of our time. However, such an approach may not work as the technologies employed by Paleoindians are not likely to be applicable to other time periods when interested in questions of any specificity. Therefore, it would take several sites in various regions of the country or from around the world. That is, given the variation in raw material quality, technologies employed, tools produced, and other such factors, a method or methods developed for one time period in one region may differ from what is needed in another part of the world. Given this and a commitment to attempting to produce exemplars, we would recommend more in the way of comparative analyses. Such comparisons with assemblages from other regions and time periods could prove particularly instructive and gain larger readership. Thus, there should be a greater concerted effort from various researchers (skeptics), who will "test" the method by either following the example or challenging the results.

In conclusion, a more thorough study is in order to determine if a TO approach has become "paradigm-like." However, it could be argued that we are in something of a normal-science phase of employing a TO approach. That is, the basic goals and methods are in place, and most work is to further refine this approach. We feel that such a phase of lithic analysis is healthy and do not anticipate a revolution in lithic studies that would mean completely doing away with a TO approach, rather such a revolution would need to incorporate current goals and methods, and take us to a new level of understanding. In the meantime, we will continue to work to learn more from lithics.

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