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Ethnoarchaeology and the Organization of Lithic Technology

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Abstract Although the modern production and use of stone tools is rare, ethnoarchaeological research on this subject has provided important perspectives on methodological approaches to archaeological lithic analysis. Recent ethnoarchaeological research on lithics frequently takes the form of "cautionary tales," warning against the primacy of functional variables most commonly invoked by lithic analysts. I argue that lithic ethnoarchaeology would benefit from a comparative organizational framework for explaining variation in patterns of stone tool use that takes into account the predictability and redundancy of the location and timing of technological activities. Understanding the underlying causes of modern patterns of stone tool use, in turn, offers a framework for exploring sources of lithic technological variation in the archaeological record. I also argue that technological analytical perspectives, such as the chaîne opératoire and sequence of reduction approaches, can benefit from the insights gained through lithic ethnoarchaeological research, helping us define important analytical concepts and identify appropriate units of analysis.

Keywords Stone tools · Ethnoarchaeology · Organization of technology · Chaîne opératoire · Sequence of reduction

Introduction

Since the 1960s, experimental knapping has formed the basis for the analysis of archaeological lithic assemblages, and archaeologists interested in stone tools now routinely learn to knap as an aspect of their training. Ethnoarchaeological studies of modern forager technology also have contributed a great deal to modern lithic

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analytical perspectives and are cited frequently (see Skibo 2009 for review and citation patterns). A significant number of ethnoarchaeological studies specifically focus on the few remaining cases of modern stone tool use. The value of this line of research is clear because it offers the unique opportunity to view stone tool use in its wider cultural contexts. Yet the influence of lithic ethnoarchaeology has been muted, in spite of the profound impacts that experimental knapping and forager ethnoarchaeology have had on approaches to archaeological lithic analysis.

In presenting a review of recent research, I argue that lithic ethnoarchaeology has been theoretically, methodologically, and contextually fragmented and that this fragmentation has hindered potential application to the archaeological record. Lithic ethnoarchaeological studies often take the form of either cautionary tales or context-specific anecdotes warning against the primacy of commonly considered materialist variables. I argue that such studies (with important exceptions) have generally failed to produce substantive analytical concepts with which to approach archaeological lithic assemblages.

The cautionary concerns manifested in lithic ethnoarchaeological research are sometimes valid; common large-scale variables such as type of subsistence economy and broad categories of tool function often do not satisfactorily explain variation in lithic technology. I disagree, however, with the frequent conclusion of these cautionary tales that ideational phenomena are primarily responsible for structuring the characteristics of stone tool industries. Instead, I argue that conditions of technological organization more specifically determine the ways in which people make, use, reduce, and discard stone tools. These organizational conditions include the predictability, redundancy, and intensity of tasks requiring tools, as well as the location and timing of episodes of tool manufacture. These issues are often ignored in both ethnoarchaeological and archaeological research; I argue that a fuller consideration of these variables can help explain many of the similarities and differences documented in cases of modern stone tool use.

I propose that ethnoarchaeological studies of stone tools would benefit from a technologically oriented and comparative analytical framework such as the organizational approach. As O'Connell (1995) argues, ethnoarchaeological studies are unique in their capability of addressing directly the issue of *why* cultural systems have specific properties and the ways in which these properties shape the archaeological record. For lithic ethnoarchaeology, understanding the *causes* of technological variation represents actualistic knowledge that is not simply historically or regionally contingent; instead it can be used to interpret archaeological phenomena outside specific ethnographic circumstances. A comparative view of lithic ethnoarchaeological studies also offers a range of variation with which to understand the causal factors that underlie similarities and differences between cases.

I also argue that technological lithic analytical perspectives would benefit from a consideration of the implications of lithic ethnoarchaeological research. Specifically, ethnoarchaeological studies of stone tools offer a framework for linking the sequential ordering of lithic debris and processes of tool reduction with strategies of design and the organizational issues of planning and the immediate contingencies of use. Furthermore, ethnoarchaeological observations of tool production, use, and discard can address difficulties with the application of the key analytical concepts of the organizational approach, such as curation and expediency.

Here I present a comparative synthesis of lithic ethnoarchaeological research aimed at linking the characteristics of lithic technological systems with the various cultural dynamics that have produced them. I also discuss the implications of lithic ethnoarchaeology for technological analytical concepts and for making sense of operational classifications of lithic debitage through the chaîne opératoire and sequence of reduction perspectives. I conclude with an archaeological case study—an analysis of Acheulean handaxes from the African Early Stone Age (ESA). Using the organizational approach and principles derived from the review of lithic ethnoarchaeological research, I argue that differences in the characteristics of Acheulean assemblage composition resulted from the spatial segregation of various technological activities and that handaxes were multifunctional curated items of personal toolkits.

Organizing an ethnoarchaeological approach to lithic technology

Numerous review papers in the last two decades have pointed to debate concerning the purpose, scope, analytical practices, and impact of ethnoarchaeological research as it pertains to archaeological methods (Arnold 2000; Arthur 2006; Costin 2000; David 1992; David and Kramer 2001; Hegmon 2000; O'Connell 1995; Roux 2007; Skibo 2009; Stark 2003; Sullivan 2008). A recurrent theme of these reviews is the concern that ethnoarchaeology has had relatively little impact on the broader field of archaeology: "Once in a while ethnoarchaeologists happen upon something interesting and applicable, though insignificant, but mostly they toil in obscurity working on problems that provide only wrist-slapping cautionary tales rather than something that anyone can actually apply to the analysis of their piles of sherds and chipped stone" (Skibo 2009, p. 29).

These reviews also converge on their recognition of the complaint that ethnoarchaeological studies have been limited in their application due to the lack of clear and direct correlates between past and present phenomena. They point to practical difficulties on the part of archaeologists in making use of ethnoarchaeological information for these reasons. Overcoming this major set of difficulties represents one of the central foci of these reviews, yet there seems to have been little change in the situation despite the pleas of frustrated ethnoarchaeologists.

Much of the ethnoarchaeological review literature has been concerned with either ceramics or hunter-gatherers; there are fewer ethnoarchaeological studies of stone tools, and they are less directly analogous with most archaeological situations than, for example, Kalinga ceramics production is with most Holocene archaeological contexts (Beck 2006; Stark 2003; Stark and Skibo 2007). Given broader difficulties in constructing an ethnoarchaeology that is relevant to mainstream archaeology and concerns that are specific to the ethnoarchaeology of stone tools, two questions are apparent: Is it worth the effort to try to make lithic ethnoarchaeology more applicable to archaeological data? and How can we develop strategies for learning about the archaeology of lithics based on principles derived from ethnoarchaeology?

I argue that ethnoarchaeology offers varieties of actualistic information that experimentation cannot and is, therefore, indispensible, in spite of the vagaries of the modern contexts of stone tool production. By structuring lithic ethnoarchaeology with a technologically oriented approach, we may start to understand the underlying causes of variation in stone tool use in comparative terms. In other words, we may learn about *why* individuals make and use stone tools in the ways that they do. Rather than being limited to direct analogs or cases of historical continuity, an understanding of technological variation and causation is applicable to the full range of archaeological contexts.

Research on stone tools and actualistic approaches

The fact that the manufacture and use of stone tools has been rare during the historical development of the field of archaeology has certainly hindered the development of analytical methods (Whittaker 1994). As Heizer (1962) observed, at the onset of the Enlightenment in Europe, natural historians (and incipient archaeologists) still held views that stone tools were the result of lightning strikes or the work of elves. It was only with European colonization of the Americas, Africa, and Australia that stone tools were observed in cultural contexts and their actual role in the archaeological record was recognized (Weedman 2000). Even then, most stone tool use had ceased by the true formation of the academic field of anthropology (Bourke 1890). Thus, in spite of a few precocious efforts at systematic study (e.g., Holmes 1894), stone tools remained largely unfamiliar to archaeologists deep into the 20th century.

Early research on stone tools was directed by the "type fossil" approach, which used diagnostic lithic forms as chronological tools for the relative dating of archaeological units (e.g., Garrod and Bate 1937; Peyrony 1930). Bordes (1961) innovated by constructing a cumulative typological frequency approach as a systematic analytical tool for the comparison of lithic assemblages across sites, regions, and time periods—the foundation of modern Paleolithic research on stone tools. Such typological approaches were not limited to the European Paleolithic but also were in keeping with broader culture-historical goals of Americanist archaeology prior to the 1960s (Trigger 2006). As Bordes' so-called "functional debate" with the Binfords (Binford 1973; Binford and Binford 1966; Bordes 1961) demonstrated, there was little concern for how stone tools were actually used prior to the development of the New Archaeology. Furthermore, to the extent that there was interest in function, "common sense" speculation was the only available tool for assessing it (Kuhn 1995). With the onset of the New Archaeology, there was increasing concern for how stone tools were made, used, and discarded in the past, and how they could be used to learn from the archaeological record.

Beginning with Crabtree and Bordes, there was a proliferation of experimental studies in which archaeologists learned knapping techniques, replicated archaeological technologies, and applied implications to archaeological cases (Amick and Mauldin 1989; Bordes 1969; Bradley 1975; Callahan 1979; Crabtree 1966; Dibble 1987; Dibble and Whittaker 1981; Flenniken and Raymond 1986; Inizian et al. 1992; Keeley 1980; Newcomer 1971; Sheets and Muto 1972; Toth 1982, 1985;

Whittaker 1994). Experimental studies have been central to the development of sophisticated approaches to stone tool technology, and knapping is now a commonplace activity for lithic analysts (e.g., Whittaker 1994, 2004). The strengths of experimental research are that (1) it reconciles the rarity of stone tool technology in the modern world; (2) it allows for the controlled isolation of relationships between certain kinds of raw materials, technical gestures, and other aspects of manufacture/use and the characteristics of resulting lithic objects; (3) it provides an analytical vocabulary for talking about the morphological features of stone tools and their manufacturing debris; and (4) it allows for the reconstruction of the plausible technological roles of stone tools within certain kinds of past behavioral dynamics.

Experimental knapping has been the basis of much of the modern technological approach to lithic analysis, especially the chaîne opératoire and sequence of reduction perspectives. Knapping has served as a reference for the identification of the sequential position of debitage and also for relating its formal characteristics with the technical actions that produced it (Bar-Yosef and van Peer 2009; Boëda 1995; de la Torre and Mora 2008; Inizian et al. 1992; Pelegrin 1990; Pelegrin et al. 1988; Tixier et al. 1980; van Peer 1992; Whittaker 1994). Likewise, knapping provided the basis for understanding the transformational systematics of stone tools inherent within the sequence of reduction approach (Dibble 1987, 1995; Flenniken and Raymond 1986; Frison 1989; Kuhn 1990, 1991, 1992, 1995; McPherron 2000; Rolland and Dibble 1990; Shott 2007; Shott and Weedman 2007). Views differ concerning the similarities and differences between the chaîne opératoire and sequence of reduction approaches (Andrefsky 2009; Bar-Yosef and van Peer 2009; de la Torre and Mora 2008; Sellet 1993; Shott 2003, 2007), and it is perhaps beyond the scope of this paper to address this issue completely. Each has its roots, however, in knapping as a method for linking the formal characteristics of debitage seen in the archaeological record with the sequential actions that produced it.

Ethnoarchaeology has been the other strategy for building analytical frameworks for approaching the lithic archaeological record. Though vitally important, experimental research is inherently limited by its inability to view the organization and design of technological systems in dynamic living contexts and the constraints those impose. Knowing how to make handaxes, plausible ways in which they were used, and their effects on various kinds of raw materials is important, but this information can only be the basis for speculation about the operation of Acheulean technology as a whole system in its prehistoric context (McCall and Whittaker 2007). Ethnoarchaeological studies of technology, in contrast, while limited in their ability to control various conditions, do far more to address the relationship between the design, manufacture, maintenance, recycling, and discard of tools in the context of the everyday economic problems in which they operate.

One important element of this line of ethnoarchaeological research has been the study of nonlithic technological systems among mainly forager societies (Bartram 1997; Binford 1977, 1978, 1979; Bleed 1986; Greaves 1997; Hitchcock and Bleed 1997; O'Connell 1995; Oswalt 1976; Shott 1986; Skibo 2009; Torrence 1983; Ugan et al. 2003). Beginning with Binford's (1977) study of the Nunamiut, ethnoarchaeological research on nonlithic hunting technology has been central in exploring the place of tools within their broader systematic context and the archaeological derivatives of tool use. Binford's (1977, 1978, 1979) series of papers outlining the concept of curation has served as the basis for the organizational approach to technology (Andrefsky 1994, 2009; Bamforth 1986, 1991, 2003; Bamforth and Becker 2000; Greaves 1997; Kelly 1988; Kelly and Todd 1988; MacDonald 2009; Nelson 1991; Parry and Kelly 1987; Sellet 2004; Shott 1986, 1996; Torrence 1983).

Though variably defined, the organizational approach broadly views technology as an organized system with components designed to address future anticipated needs and adapted to deal with the contingencies of immediate conditions. The organizational properties of technological systems are brought about by dynamics of settlement, mobility, and subsistence. In turn, the processes of archaeological site formation are shaped by these organizational properties of technological systems and the spatial segregation of certain activities. Thus the organizational approach attempts to link the characteristics of archaeological assemblages at various landscape locations with aspects of technological organization and, on that basis, to construct inferences about broader cultural dynamics.

Following Binford's (1977, 1978, 1979) explication, the term curation has been the subject of a great deal of discussion and debate. Binford views curation as a technological strategy for assuring the presence of appropriate tools for anticipated needs. This strategy consists of the staging of tool manufacture and maintenance during periods of "downtime" in the presence of necessary raw materials and the transport of resulting tools in anticipation of their need in the field (see also Bleed 1986). The concept was foundational to the organizational approach, even though some archaeologists have objected to this view based on the difficulty of its operational definition in terms of archaeological remains (Andrefsky 2006, 2009; Nash 1996; Odell 1996; Shott 1996). Specifically, how might one recognize archaeologically the anticipation of future needs or the transport/retention of an artifact without recognizable modification? In addition, Shott (1996) argues that Binford was inconsistent in his own definition of curation and that he actually outlines a number of related ideas subsumed under the curation label. Stemming from these concerns, many archaeologists have attempted to define and quantify curation based on the extent of tool retouch, typically involving the calculation of retouch indices (see Andrefsky 2009 and Horowitz 2010 for recent reviews). In this paper, however, I use curation in the general sense of the retention of tools in anticipation of future technical needs, rather than referring to retouch-based indices.

The *design theory* framework is an important aspect of the organizational approach, which views technology as an optimal response to technical problems resulting from various economic activities, their demands, and constraints (Bamforth 1986; Bamforth and Bleed 1997; Bleed 1986, 1991, 2001; Hitchcock and Bleed 1997; Horsfall 1987; Kleindienst 1975; Oswalt 1976; Sandgathe 2004; Schiffer et al. 2001; Torrence 1983). Ethnoarchaeological studies of forager technology have made important contributions to this approach by elucidating the relationship between the design of tools, the technical problems inherent in daily economic activities, and broader technological strategies resulting from subsistence and mobility patterns (Bartram 1997; Binford 1977, 1978, 1979; Bleed 1986; Churchill 1993; Gould 1980a; Gould et al. 1971; Greaves 1997; Hayden 1979; Hitchcock and Bleed 1997; Nelson 1991; Oswalt 1976). Design theory is central to the study of technological strategies, such as curation, as it offers explicit links between the functional properties of tools and the future needs for which they are designed.

As a toolkit for making inferences from the archaeological record, the organizational approach relies on the synthesis of ethnoarchaeological observations and documented ethnographic variation. This offers the opportunity to link patterns of technological organization with the cultural dynamics that produce them. For example, Binford (1980) sought to link forms of forager technological organization with strategies of mobility and settlement systems (see also Binford 2001; Kelly 1983, 1995; Shott 1986). Thus it is evident that the organizational approach to ethnoarchaeology has benefited from a comparative perspective and that a comparative perspective on lithic ethnoarchaeology has a great deal to offer to the organizational approach to stone tool technology.

Lithic ethnoarchaeology and the issue of analogy

In examining the limited impact of ethnoarchaeology on mainstream archaeology, a number of recent reviews have cited the lack of clear and direct analogies with archaeological cases as a possible explanation (Arnold 2000; David and Kramer 2001; O'Connell 1995; Skibo 2009; Skibo et al. 2007; Stark 2003); this is no doubt the case for lithic ethnoarchaeology as well. Perhaps the main reason for this is that most lithic ethnoarchaeological studies have been concerned with sedentary peoples (at least at the time of their observation). In contrast, the bulk of archaeological lithic analyses are concerned with mobile foragers, and mainstream lithic analytical perspectives, such as the organizational approach, are concerned with addressing issues of mobility (Andrefsky 1994; Bamforth 1991; Bettinger 1991; Blades 2003; Chatters 1987; Jeske 1989; Kelly 1988; Kelly and Todd 1988; McCall 2007; Parry and Kelly 1987; Sellet 2006; Shott 1986; Thacker 2006). Thus direct analogies between lithic ethnoarchaeological studies and archaeological cases are few and far between.

Of course, few archaeologists would admit to the desire for direct ethnographic analogies, on the heels of decades of serious critical discussion (Binford 1967; Gould and Watson 1982; O'Connell 1995; Wobst 1978; Wylie 1985; Yellen 1977). The opposite of a direct analogy is the ethnoarchaeological cautionary tale, which effectively denies the basis for an archaeological approach based on observation of contradictory ethnographic conditions. Cautionary tales also are the subject of criticism (Hegmon 2000; O'Connell 1995; Roux 2007; Skibo 2009), as they offer no systematic inferential insights beyond their narrowly focused target.

The use of ethnoarchaeological studies to construct robust analytical frameworks for approaching the archaeological record rests on the distinction between *analogical* and *referential* thinking. Analogical reasoning rests on the assumption of what Gould (1965) calls "substantive" uniformitarianism, which requires close contextual similarity or direct historical continuity between past and present phenomena (see also Cameron 1993; Gould and Watson 1982). Examples of substantive analogy include using the ethnography of a given people to study their immediate archaeological ancestors (i.e., the "direct historical approach") or making the direct equation of an ethnographically known phenomenon with some assumed archaeological counterpart.

In addition to the assumption of substantive uniformity between past circumstances and modern cases, analogical thinking frequently manifests the tendency of ethnoarchaeological research toward cautionary tales, the recognition of instances where the assumption of substantive uniformity is false. Analogical reasoning is therefore limited to either the isolation of similar past and present phenomena or the demonstration that such presumed similarities do not exist. O'Connell (1995, p. 208) characterizes this situation: "Cautionary tales point to interpretive problems but usually provide no means of resolving them. Analogies help one stipulate the temporal and spatial limits of ethnographically recorded behavior but offer no guidance in interpreting, sometimes even identifying, archaeological evidence of anything else. Even where they accurately characterize past behavior, they cannot explain it." Analogical thinking based on the assumption of substantive uniformity obviously cannot be used to understand the vast majority of archaeological phenomena, which do not have clear ethnographic correlates (Wobst 1978).

Referential reasoning, in contrast, relies on the recognition of linkages between the dynamics of human behavior, its organization into cultural systems, and resulting patterns of material remains that constitute the archaeological record (Binford 1981). Referential reasoning rests on the principle of what Gould (1965) calls "methodological" uniformitarianism. In contrast with substantive analogy, methodological uniformitarianism does not assume exact constancy in the observable characteristics of phenomena over time but rather uniformity in the laws that govern them and therefore the theoretical principles that may be used to explain them. Referential reasoning is a process of building knowledge concerning the methodological uniformities that link the characteristics of the archaeological record and the systems of human behavior that produced them. The process of referential reasoning is necessarily comparative in its exploration of methodological uniformities.

In this pursuit, O'Connell (1995) argues that general theory capable of explaining patterns of human behavior is required to build analytical frameworks for studying archaeological situations outside those seen ethnographically (Binford 1981; Roux 2007; Schiffer 1988; Wobst 1978). I argue that lithic ethnoarchaeology needs a comparative technological perspective as the basis for its theoretical framework in terms of understanding the causes of various patterns of stone tool use. Such an approach would allow the construction of a body of knowledge composed of the methodological uniformities that link specific patterns of lithic technology and the dynamics of cultural systems that produce them. This implicates the necessity of structuring a comparative lithic ethnoarchaeology focused on the technological causes of variation within lithic assemblages.

More comparative research would represent a shift in existing research trajectories. Early lithic ethnoarchaeological studies were mostly cautionary tales concerning problems with lithic analytical frameworks having to do with the emic reality of formal tools (Gallagher 1977; Gould et al. 1971; MacCalman and Grobelaar 1965; White 1967; White and Thomas 1972). Although later studies increased in sophistication by focusing on the implications of modern lithic technology for understanding issues including the reality of stone tool traditions, the social contexts of learning, and gender (Arthur 2010; Hampton 1999; Petrequin and Petrequin 1993; Sillitoe and Hardy 2003; Weedman 2000, 2002, 2006), these often retain a cautionary theme or present the basis for some specific form of substantive analogy.

Weedman (2006), for example, offers a description of the manufacture, hafting, and use of scrapers by the Gamo hideworkers of southern Ethiopia. Yet her conclusion is that assumptions of functional determinism that underlie modern lithic analysis are untrue—a cautionary tale not dissimilar from the results of earlier research in the same region (Clark and Kurashina 1981; Gallagher 1977). Weedman negates the functional properties of different scraper designs, differential access to raw materials (including wood for hafts and mastics), and differences in local environments as adequate explanations of scraper variation—all frequently invoked in archaeological lithic analyses. Instead, she points to social and political factors as prime movers and states that her study "reveals how material culture reflects changing relationships in global, regional, and local webs of interaction" (Weedman 2006, p. 227). While these are all important ethnographic issues, they are difficult building blocks with which to construct systematic and comparative referential frameworks for archaeological analysis.

In short, a technological orientation would benefit lithic ethnoarchaeology in two major ways. It offers a theoretical framework for explaining the characteristics of lithic assemblages in terms of both specific everyday problems and the broader dynamics of cultural systems. It provides a common vocabulary and set of analytical concerns with which to structure a comparative approach to lithic ethnoarchaeology. The following examples of lithic ethnoarchaeological research help illustrate these benefits.

Reviewing ethnoarchaeological observations on stone tool technology

Here, I present a comparative review of ethnoarchaeological studies of stone tools in organizational terms (Table 1). To begin, there are two types of diversity in the primary ethnoarchaeological research that require attention. First, such studies cover a broad range of cultural, economic, environmental, and geographic contexts—a major strength for constructing a comparative framework. Second, lithic ethnoarchaeology has been carried out from a wide array of theoretical and methodological perspectives and concerns many different questions (Roux 2007). Thus the kinds of information reported in these studies vary a great deal, and it is not always possible to find details that might be important for building a technological analytical framework.

I use the structure presented in Nelson's (1991) outline of the organizational approach as a framework for description and analysis. I begin with a discussion of the environmental conditions, cultural systems, and broad economic strategies within which modern stone tool use is found. I outline the specific economic activities, technical problems, and technological strategies in which stone tools are used. I relate the design of stone tools to the demands and constraints derived from

Table 1 Ethnoarchaeological accounts of stone tool use and related design morphology of stone tool assemblages

Ethnographic case	Raw material	Raw material acquisition	Manufacture strategies	Most common tasks done with stone tools	Characteristics of stone tool assemblage	References
Western and Central Desert Aborigines (Ngatatjara, Nyatunyatjara, Ngatjara, and Pintupi)	Chert, chalcedony, quartzite; quarrying of primary deposits and collection of derived pieces	Acquisition at site of task; quarrying of Levallois-like flakes from high-quality sources for making "men's knives"	Expedient flaking at sites of task, curation of Levallois-like "men's knives"	Cutting, butchery, woodworking	Expedient flakes, scrapers, core adzes, "men's knives"	Binford 1986; Binford and O'Connell 1984; Gould 1978, 1980b; Gould et al. 1971; Hayden 1979; O'Connell 1974; Tindale 1965
Highland Maya glass knappers	Bottle glass; garbage accumulations	Storage of "bottle cores" at permanent residential locations	Expedient flaking, retouch of flakes	Woodworking, wood engraving, hide scraping, bone smoothing, ritual bloodletting	Low edge-angle glass flakes, steep edge-angle glass flakes, retouched glass flakes	Deal and Hayden 1987; Hayden 1987; Hayden and Nelson 1981
Brazilian Xeta foragers	Mostly cherts	Collection near residences during horticultural and foraging activities	Expedient flaking	Woodworking, cutting, butchery	High edge-angle flakes, high edge-angle cores, low edge-angle flakes	Laming-Emperaire 1964; Miller 1979
Namibian/Angolan Tjimba foragers	Silcrete, quartzite; mainly fluvial gravels	Local sources coincident with residential locations	Expedient flaking, retouch of flakes	Cutting, butchery	Expedient flakes	MacCalman and Grobelaar 1965
New Guinea highlanders (Wola, Una and Dani)	Chert, glassy basalt, rhyolite; cobbles in erosional features and gardens, boulders in river basins	Collection during horticultural activities; specialized collection of stone from river basins for adze knapping	Expedient flaking; specialized manufacture of trihedral adzes	Woodworking, cutting, digging	Expedient flakes, bifacial/trihedral groundstone adzes	Hampton 1999; Petrequin and Petrequin 1993; Shott and Sillitoe 2001, 2004, 2005; Sillitoe and Hardy 2003; Stout 2002; Strathern 1969; White 1967; White and Thomas 1972

Table 1 continued

Ethnographic case	Raw material	Raw material acquisition	Manufacture strategies	Most common tasks done with stone tools	Characteristics of stone tool assemblage	References
Ethiopian hideworkers (Gurage, Galla, Gamo, Konso)	Chert, obsidian, bottle glass; mostly distant from residential locations	Extensive walking to chert sources controlled by family groups. Purchase of stone at markets	Scrapers retouched for fitting into several kinds of scraper handles	Hide scraping	Convex retouched scrapers	Arthur 2010; Brandt 1996; Gallagher 1977; Clark and Kurashina 1981; Shott and Weedman 2007; Weedman 2000, 2002, 2006
Siberian Chukchi reindeer herders	Glassy basalt, quartzite, chert; fluvial gravels	Embedded acquisition of stone during other hideworking activities	Flaking of pebble cores to produce scraper blanks, retouch of flakes to make scrapers that fit into handles	Hide scraping	Convex retouched scrapers	Beyries 1997; Beyries et al. 2001; Beyries and Rots 2008; Takase 2004
Turkish threshing-sledge blade knappers	Cherts	Mining from subterranean contexts	Knapping of prismatic blades, backing	Sale at market, then incorporation into threshing sledges	Prismatic blades, often backed	Bordaz 1970; Whittaker et al. 2009

these technological strategies, along with design constraints imposed by issues of raw material supply. I discuss the manufacture and use of tools in the context of design demands and raw material supply constraints. Finally, I describe the organizational characteristics of activities relating to stone tool production, use, and discard, as well as the implications of these for the formation of archaeological assemblages.

As a disclaimer, I ignore early ethnographic or ethnohistorical accounts of stone tool use done outside an explicitly archaeological or ethnoarchaeological framework (e.g., Gusinde 1931; Outes 1905; Roth 1904; Spencer and Gillen 1904), though these are clearly valuable for lithic researchers. There also are historical cases, for example, English gunflint knappers from the 18th and 19th centuries, that offer interesting ethnographic facts and were useful to early archaeologists (see Whittaker 1994 for discussion). Certain accounts, such as early ethnographic descriptions of mobile forager lithic technology from Australia, may be extremely relevant to the archaeological contexts of past foragers. Contact-era historical accounts, however, rarely contain the kind of detail and concern for the relationships between tools, technological strategies, and cultural/economic contexts necessary for the central issues of this paper.

The economic contexts of modern stone tool use

While diverse in geographical setting and environmental conditions, the majority of modern stone tool use occurs in small-scale agricultural and/or pastoralist economies. Cases of modern stone tool use among foragers are comparatively rare, although there are important studies from Australia, southern Africa, and Amazonia. An isolated case—the production of blade inserts for threshing sledges in Turkey, Cypress, and elsewhere in eastern Europe and the Near East—represents knapping within an intensive agricultural economy and complex market environment.

Among the case studies are two examples of hide scraping in the context of pastoralism: the hideworkers of southern and central Ethiopia, who participate in an economy of cattle and goat herding mixed with small-scale agriculture, including the Mafaed, Gurage, Galla, Gamo, and Konso (Arthur 2010; Beyries and Rots 2008; Brandt 1996; Clark and Kurashina 1981; Gallagher 1977; Weedman 2000, 2002, 2006), and the Siberian Chukchi, who herd reindeer (Beyries 1997, 2002; Beyries and Rots 2008; Beyries et al. 2001). Aside from obvious differences in environment and livestock, there also are important cultural and economic distinctions. The Gamo and Konso (my focus here) live in small permanent villages, mix subsistence agriculture with pastoralism, and participate in Ethiopia's market economic system. Gamo and Konso social structures are characterized by a caste system linking individuals and lineages to specific professions with ascribed social status (Arthur 2010; Weedman 2000, 2006). Among the Gamo, men are the hideworkers, and they are tied to villages through a patrilocal postmarital residence system. The Konso maintain a system of hereditary endogamy, and women are responsible for hideworking and associated stone tool manufacture.

In contrast with the Ethiopian cases, the Siberian Chukchi are fairly mobile, mixing hunting and other foraging activities during the summer and participating in market economic systems in urban centers (including schooling for children) during the harsh Siberian winter (Beyries 2002; Beyries et al. 2001). The Chukchi are relatively egalitarian; their economic systems exhibit a much smaller degree of economic specialization than the Gamo and Konso, and their division of labor occurs largely along the lines of age and gender.

Village agriculture characterizes the economic systems of two of the ethnoarchaeological cases: the peoples of highland New Guinea (including the Duna, Una, Wola, and Dani) and the highland Maya from Guatemala and Mexico. The cases from New Guinea share many characteristics with the subjects of other "classic" ethnographies from Oceania. Villages have small population sizes and a chiefdom political structure with moderate levels of lineage-based social and political inequality (Hampton 1999; Shott and Sillitoe 2004; Sillitoe and Hardy 2003; Stout 2002; Strathern 1969; White 1967; White and Thomas 1972). Agricultural economies are largely organized at the subsistence level and are based primarily on the farming of sweet potatoes and pigs. Some Maya groups in highland Guatemala and Chiapas practice subsistence maize agriculture and a range of craft production activities. In contrast with the New Guinea cases, they are more connected with national political, economic, and religious structures (Deal and Hayden 1987; Hayden 1987; Hayden and Nelson 1981).

There also are several forager societies represented in these case studies. The bulk of these come from the central, northern, and western arid regions of Australia (Binford 1986; Binford and O'Connell 1984; Gould 1980b; Gould et al. 1971; Hayden 1979; O'Connell 1974; Tacon 1991; Tindale 1965). Whereas early accounts were made on mobile groups (e.g., Tindale's 1965 influential study of *tula* scraper manufacture and hafting), later descriptions document either predominant sedentism or mobility substantially augmented by modern technologies like automobiles (Binford 1986; Binford and O'Connell 1984).

There are two lesser-known accounts of stone tool use by mobile foragers. MacCalman and Grobelaar's (1965) report on the Tjimba of northern Namibia documents stone tool use by relatively mobile pastoralist/foragers. Though frequently cited, this study is concerned primarily with simply demonstrating the continued use of stone tools, and it is doubtful that such activities continue in Namibia today. In Amazonia, the Guarani-speaking Xeta people mixed foraging and horticulture and were fairly mobile (Laming-Emperaire 1964; Miller 1979). The Xeta were "discovered" by Western observers in 1948, and at the time of their ethnoarchaeological study in the 1960s only six individuals remained. All stone tool-related activities were staged in reconstructed settings.

Finally, the manufacture of flint threshing-sledge inserts has been observed in a highly specialized economic context of large-scale intensive agriculture and extensive trade within a market economic system (Bordaz 1970; Whittaker et al. 2009). Although the manufacture of such items seems to have ceased, it was directly observed by Bordaz (1970) in Turkey during the 1960s and is known to have occurred recently throughout the eastern Mediterranean and Near East (Whittaker et al. 2009).

Economic activities and technological strategies

There is clearly a wide range of social and economic contexts in which modern stone tool use is found. Likewise, there is a great deal of diversity in terms of the specific economic activities and resulting technological strategies that have brought about stone tool use. Even in cases where stone tools are produced for the same technical purposes (e.g., hide scraping or woodworking), the technological strategies within which stone tools are made and used are frequently quite different.

For example, the Gamo, Konso, and Chukchi are all linked with pastoralist activities, and stone tool use fits within the resulting context of hide scraping. However, the technological strategies at work in these cases are quite divergent. For the Gamo and Konso, hide scraping occurs as a part of the specialist production of leather items (especially bedding) from cowhides for exchange in market contexts (Arthur 2010; Beyries and Rots 2008; Weedman 2000, 2002, 2006). Resulting economic strategies are very narrowly aimed at repeatedly producing one specific set of goods. In addition, the pathways for producing the tools necessary for hideworking tasks are redundant, predictable, and linear. Hideworking always occurs in the same location—workshops or activity areas attached to residential units, where hides, scraper handles, scrapers, and the raw materials for tool manufacture are stockpiled. If one considers the life history of a scraper from the acquisition of stone to its ultimate discard (e.g., Shott and Weedman 2007), then all manufacture, maintenance, and use activities occur in essentially the same places and under the same conditions.

The Chukchi, in contrast, depend on reindeer hides as the most basic element of their economic system as mobile groups living in the Siberian Arctic (Beyries 1997, 2002; Beyries et al. 2001; Beyries and Rots 2008). Hides form the basis of tent covers and clothing necessary to deal with the Arctic eastern Siberian environments. Such technologies composed of reindeer hides are universally required, their manufacture and repair occur as ongoing processes in a wide variety of places and contexts, and specialization in terms of their production is structured according to age and gender (done mainly by older adult women). The conditions under which hides are scraped vary a great deal, as do the circumstances of stone tool manufacture, use, and repair. Thus, while some of the specific tasks for which stone tools are used may be similar to those described among the Gamo and Konso, the role of stone tools within the wider technological strategies of the Chukchi is quite different. There is no doubt that this accounts for the substantial differences in the life histories of scrapers in these two contexts.

The same is true of stone tool use for nonscraping tasks. Perhaps one of the most complex cases in this regard is that of New Guinea highlanders. Agricultural activities require a number of wooden tools for a range of tasks related to planting, maintaining fields, and harvesting. Expedient flakes are frequently used in the manufacture of the wooden components of technology, such as handles for tools, digging sticks, bows, and arrows (Hampton 1999; Sillitoe and Hardy 2003; Strathern 1969; White 1967; White and Thomas 1972). As with the Gamo and Konso, the manufacture of stone tools in these contexts occurs in relatively redundant situations, with both stone tools and raw materials stored at residential units (Sillitoe and Hardy 2003; White and Thomas 1972). In addition, stone tools are not generally involved in the direct extraction or processing of food resources.

The other major type of stone tool manufacture in highland New Guinea is the production of stone adzes by specialist knappers (Hampton 1999; Lemonnier 1986; Petrequin and Petrequin 1993; Stout 2002). While the technological role of such objects is clear—cutting down trees for the purposes of clearing agricultural land and attaining wooden raw materials for constructing structures and other tools—they have transformed into a prestige good and a symbol of wealth. This is especially true since the introduction of metal axes, which are far more efficient than their stone counterparts (see Salisbury 1962 for a discussion of the effect of the introduction of steel axes on the economic role of stone adzes/axes in terms of marriage, status, and wealth). This situation is further complicated by the fact that knapping is only one stage of the manufacture of stone adzes; a well-knapped preform saves time grinding (the most laborious part of the process) and adds to the aesthetic value of the final product (Stout 2002).

Highland Maya agricultural systems necessitate many of the same kinds of tasks as among New Guinea highlanders, especially in terms of the manufacture of other tools. Although the Maya buy industrially produced metal tools, such as axes and hoes, they frequently replace the handles, which require their own manufacture (Deal and Hayden 1987; Hayden 1987; Hayden and Nelson 1981). Knapped glass tools made from broken bottles are used in the finishing stages (i.e., the final smoothing) of wooden handle manufacture or repair. The Maya also use stone tools in making a number of bone, horn, and leather tools. In addition, knapped glass is integrated into a number of objects used in ritual bloodletting (Deal and Hayden 1987; Hayden 1987; Hayden and Nelson 1981). The knapping of glass implements is again redundant in terms of its location and technological context, which is attached to residential units.

As with the previous two sedentary cases, the Xeta seem to have mainly used stone tools in residential contexts for the manufacture of wooden components for gardening tools and hunting weapons (Laming-Emperaire 1964; Miller 1979). They also used flakes for various small cutting tasks in residential contexts. The acquisition of raw materials is a difficult subject to address given the reconstructive nature of the Xeta case, but it seems to have occurred in the vicinity of residential centers during gardening activities or during foraging excursions. Similarly, the Namibian Tjimba produced wooden tools and carried out a number of cutting tasks with stone tools at residential units (MacCalman and Grobelaar 1965). As with the New Guinea and Maya cases, most stone tool use among the Xeta and Tjimba seems to have occurred in residential units, where there was redundancy in the scheduling of technological activities.

In Australia, foragers use a wide variety of wooden implements, hafted stone tools (e.g., points, scrapers, adzes), and unhafted flakes (Binford 1986; Binford and O'Connell 1984; Gould 1980b; Gould et al. 1971; Hayden 1979; O'Connell 1974; Tindale 1965). Once again, stone tools are often used in the manufacture of other tools, especially for woodworking (Gould 1980b; Gould et al. 1971; Hayden 1979; O'Connell 1974). Steep-edged woodworking tools, including adzes, retouched unifaces, and steep-edged unmodified flakes, are sometimes hafted. Unmodified flakes with low edge angles are generally handheld and used for cutting and whittling tasks. Low edge-angle flakes are also occasionally used in small animal butchery and other food-processing tasks.

Within Australian forager groups, triangular macroblades are often hafted onto wooden handles or spears as *leiliras*, or “men’s knives” (Binford 1986; Binford and O’Connell 1984; Gould et al. 1971; Hayden 1979). These triangular flakes are sometimes described in terms of their formal similarity with Middle Paleolithic Levallois points, though the core reduction strategies responsible for their manufacture are quite different (Binford 1986; Binford and O’Connell 1984; Hayden 1979). The production of elaborately retouched points in the Kimberley region, frequently made on glass or high-fired European ceramic pieces, is thought to have continued into the mid-20th century. These “Kimberley points” also were hafted as spear points or knives (Akerman et al. 2002) and were primarily exchange items at the time of contact. Though they are sometimes placed on the ends of spears, men’s knives are often handheld and used for a wide variety of cutting tasks (Hayden 1979; O’Connell 1974).

The issue of the staging of stone tool manufacture and the location of tool use in Australia is somewhat murkier. Even by the time of the first true ethnoarchaeological studies of in these regions (e.g., Gould et al. 1971; O’Connell 1974; Tindale 1965), mobility patterns were changing rapidly and stone tool use was in the process of disappearing (Binford and O’Connell 1984). What resulted was, once again, an attempt to reconstruct stone tool manufacture and use in the “old way” (Binford 1986; Binford and O’Connell 1984; Gould 1980b; Hayden 1979). This also was done in intentionally staged episodes of technological activity and making use of modern technology (i.e., pickup trucks) for raw material transport. Obviously, this situation was not ideal for the usual goals of ethnoarchaeological research. It is apparent, however, that raw material acquisition and tool manufacture occurred under a broad set of circumstances resulting from mobility on the landscape and the immediate technical demands brought about by particular subsistence situations (Binford 1986; Binford and O’Connell 1984; Hayden 1979; O’Connell 1974). In fact, such studies of Australian forager stone tool use are the only to address directly crucial issues of mobility and situational variability.

The case of Turkish threshing-sledge blade manufacture is quite unlike the others discussed so far. This economic activity was highly industrial in nature; the final products were sold for cash in market contexts and were traded over extensive distances (Bordaz 1970; Whittaker et al. 2009). Flint was mined from large-scale deposits on the periphery of urban centers, often involving the construction of mine architecture such as large pits and even subterranean shafts. The manufacture of the sledge inserts occurred in large workshops in urban centers. These workshops were owned by specific individuals, organized in an assembly-line structure, run with a management hierarchy, and employed large numbers of craftsmen. Ultimately, the blades were sold to farmers in the region, who incorporated them as components of threshing sledges used in the separation of grain from the chaff. They were essentially replaceable components of durable and expensive threshing-sledge armatures that might last the lifetime of a farmer. In fact, threshing sledges are a collectable item for modern Turks as a reminder of older agricultural practices and an antique symbol of Turkish heritage (Whittaker, personal communication, 2009; Whittaker et al. 2009).

Technical demands, stone tool design, and form/function dynamics

Clearly there is great variability in the relationships between the technical requirements of stone tools, their patterns of design, and the ways in which they are used. Some cases, such as stone tools used for hide scraping, are characterized by designs tightly corresponding with patterns of use, others by either a high degree of versatility in the use of a single kind of tool and/or the use of different tools for the same task. This has long been recognized (Odell 1981) and is often noted in the cautionary tales of early ethnoarchaeological work on stone tools (Gallagher 1977; Hayden 1979; White 1967). There are, however, important generalizations that may be drawn beyond simply marking potential dangers for the functional analysis of stone tool technology.

Hide scraping is one recurrent use for stone tools in modern contexts. The Gamo, Konso, and Chukchi are the most prominent cases of hideworking with stone tools and are characterized by the use of "formal" retouched semicircular scrapers. The major technical demand on these scrapers is the removal of hair, fat, and other unwanted tissue while at the same time softening the leather by breaking down internal fibrous structures (Beyries and Rots 2008; Weedman 2000). This necessitates a steep working edge, generally between 60° and 90°, and a somewhat dulled surface in order to avoid tearing the hide. The Gamo and Konso use the same designs of scrapers for all phases of the hide-scraping process, while the Chukchi have several scraper designs (including one made of metal) for different phases of the hideworking process. The retouching of scrapers differs substantially between these two cases. The Gamo and Konso retouch surfaces that become too dull a number of times during the scraping of a single hide (Arthur 2010; Weedman 2000, 2002, 2006); the Chukchi may retain a variety of scrapers without further retouch for extended periods of time (Beyries 1997, 2002; Beyries and Rots 2008; Beyries et al. 2001).

Some of this variation in the design and patterns of scraper retouch stems from differences in the leather items being produced. The Gamo and Konso generally produce nonclothing leather goods, especially bedding, from thick cowhides. They also scrape their hides while wet from soaking (Beyries and Rots 2008). In contrast, the Chukchi spend a great deal of time producing leather clothing and tent covers to shield them from Arctic weather conditions. Leather clothing obviously requires different qualities from nonclothing items, such as bedding, and places different constraints on processing technology. In addition, reindeer hides are thinner and more flexible than cowhides. Arguably, the manufacture of clothing puts more demands on the later phases of hideworking involving finer, less abrasive activities to produce softer leather. The Chukchi also scrape their hides without soaking (Beyries and Rots 2008). Thus the curation of certain scrapers dulled to the point of polishing may relate to these differences in technical circumstances.

In both cases of scraper use, hideworkers report functional advantages for stone tools compared with other raw materials such as steel (Beyries et al. 2001;

Weedman 2000, 2006). This offers an important possibility for explaining the persistence of stone tool technology for the purposes of hide scraping. These cases also suggest that variation in the nature and intensity of hide scraping may have implications for scraper design and patterns of curation. Both of these cases make clear that the size and dimensions of scrapers are most strongly conditioned by the characteristics of handles—a variable not frequently considered in formal studies of archaeological scrapers (Weedman 2000, 2002, 2006).

Many of the modern cases of stone tool production are characterized by the use of expedient flakes in which individuals engage in a process of experimentation with debitage for the resolution of some immediate technical problem. White (1967, p. 409) remarks for New Guinea that "[Individuals] do not seem to regard a flake stone tool as a functional whole in the archaeological sense. Rather, they use a stone for a particular task if a particular feature of it makes it suitable for the work in hand." This statement could be equally true of other cases of expedient flake use. In general, this pattern is typified by the reduction of a core, the production of a series of flakes, and then the selection of a flake with properties that make it appropriate for the immediate task at hand. The recognition of this phenomenon as pervasive among modern stone tool use is a key point made by Parry and Kelly (1987).

In such cases, the specific tasks for which expedient flakes may be used depend on the formal characteristics of the flakes themselves. For example, Hayden (1979) describes the emic distinction between low-edge angle *(purpunpa)* and steep-edged flakes (*tjimari*; see also Gould et al. 1971). The former are used for cutting tasks and the latter for carving and scraping tasks associated with woodworking. Other determinates of flake use include the shape of a flake's edge and the suitability of a dull grasping surface; in other words, the way in which a flake fits in the hand and idiosyncratic properties of its shape for a specific task. Rather than being elements of predetermined design, these are features discovered in ad hoc fashion and worked out through a process of experimentation (Figs. 1–3).

Expedient flake use frequently occurs in the manufacture of other tools, such as the manufacture of wooden handles and implements for agricultural activities in New Guinea and the Maya highlands and the manufacture of foraging tools and weapons in Australia, Africa, and the Amazon (Figs. 4, 5). This variety of tool use occurs mostly in residential settings and rarely in the field (even among mobile foragers, such as those from Australia). This perhaps results from issues of planning, as expedient knapping can be reliably staged in residential settings where tasks are not time-sensitive (e.g., making other tools). In contrast, field activities may not allow time or raw material may be lacking for the expedient manufacture of flakes.

Lastly, Turkish threshing-sledge blades are manufactured at an industrial scale to resolve a very specific technical problem. Blades are placed in sockets on the underside of large wooden sledges, which are dragged over grain stalks to separate seeds from the shaft. The constraints on blade dimensions arise largely from the size of the sledge sockets, which were standardized over a large region of Turkey (and perhaps more broadly across the Mediterranean in earlier times; Whittaker et al. 2009). Thus threshing-sledge blades were remarkably consistent in their formal characteristics over a wide geographical area and a significant duration of time

Fig. 1 New Guinea knapper with sorted pile of debitage (photo by J. Peter White)

Fig. 2 Maya knapper with sorted piles of debitage (after Deal and Hayden 1987)

because they were tightly constrained by the size of sockets and the specificity of the task.

Raw material economy

The conservation of lithic raw material has long been recognized as a key variable influencing knapping strategies. For example, Andrefsky (1994) views the availability of lithic raw material and constraints stemming from mobility as a

Fig. 3 Alyawara knapper with sorted piles of debitage for domestic uses from a core transported to a residential camp (photo by Lewis R. Binford)

Fig. 4 New Guinea knapper using an expedient flake for carving an arrow linkshaft (after White and Thomas 1972)

primary factor shaping stone tool design. Parry and Kelly (1987) argue that raw material economy—specifically the natural abundance and stockpiling of stone at permanent residential centers—accounts for the salient patterns of expedient modern, historic, and later prehistoric stone tool manufacture. These views are largely supported, yet there are several aspects of raw material economy witnessed in these ethnoarchaeological studies that do not fit the Parry and Kelly (1987) pattern.

Cases of expedient unmodified flake use are generally characterized by the presence of locally available, adequate-quality, lithic raw material. For example, both New Guinea and Amazonian expedient flake manufacture exploit stone recovered from agricultural/horticultural fields or erosional features near residential units. The Tjimba acquire stone for knapping from derived alluvial deposits near

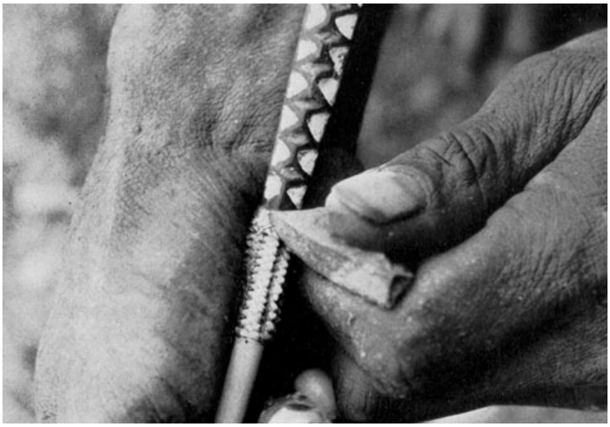

Fig. 5 Maya knapper using a glass flake for carving a wooden handle (after Deal and Hayden 1987)

their villages. Maya knappers recover bottle glass for tool manufacture out of garbage deposits. Stockpiling, however, is a more difficult issue to address with these studies. All of the cases of expedient flaking do, in fact, seem to involve the presence of small caches of raw material or flake assemblages in residential contexts. These caches, however, do not seem to be very large, and it seems that knappers do not transport stone into residential units from distant sources for the purposes of stockpiling. Perhaps when lithic raw material resources are acquired regularly during the course of everyday economic activities, even stockpiling becomes an unnecessary strategy.

Some of these cases also share a general restriction of access to metal tools as technological alternatives. The New Guinea, Amazonian, and Namibian cases have this in common by virtue of their remoteness and isolation from Western technology until recently, and glass knapping also occurs in the more remote parts of the Maya highlands. Access to metal tools also may be restricted by poverty, and stone tools may represent a cheap alternative to purchasing or manufacturing metal equivalents in isolated regions where cash and metal are scarce.

The cases of Gamo and Konso stone acquisition stand in contrast, with lithic raw material acquired in three basic ways. First, chert is acquired from primary sources restricted along the lines of kinship and clan/caste membership. Knowledge of chert sources is passed down through kinship lines, and access to chert sources within clan-based territories is restricted. Chert sources are up to four hours away from residential workshops and trips to collect stone represent a substantial investment of effort (Arthur 2010; Weedman 2000, 2006). In addition, high-quality raw materials (including chert, obsidian, and glass) are sometimes purchased at markets for considerable amounts of cash (Weedman 2000). Lastly, bottle glass is sometimes used as a cheaper but less-effective alternative raw material. In short, while perhaps not exotic in the sense of being transported over extremely long distances, Gamo and Konso lithic raw materials are often not cheap to acquire. Furthermore, the collection of raw material represents a significant opportunity cost, since that time might be spent on other economic activities.

This situation may result from the fact that stone scrapers apparently have some technical advantages over metal alternatives (Beyries et al. 2001; Weedman 2006). It is possible that the functional advantages of stone scrapers reward the considerable effort invested in raw material acquisition. Furthermore, the various technological processes of hide scraping, including the knapping of scrapers, are carried out by skilled craftspeople with very specific technical goals and techniques for achieving them. In contrast with the expedient flake use discussed above, these cases are characterized by relatively specialized patterns of resource acquisition, tool design, and the staging of technological activities.

Scraper manufacture among the Chukchi, on the other hand, is characterized by embedded raw material procurement as mobile groups move across the tundra with reindeer herds during the summer grazing season. Since the manufacture and maintenance of leather items is an ongoing process, scraper use is frequently required during residential moves, and it is difficult to anticipate in terms of its location. Lithic raw material is acquired during residential moves and logistical trips made for the collection of other resources. This is perhaps the only true case of embedded lithic raw material collection by a mobile group for which there is ethnoarchaeological data. In this case, the long-term retention of different types of worn scrapers for use in various stages of hideworking amounts to curation. This pattern is emically explained as the result of desirable properties for scraping—worn scrapers are less likely to perforate valuable hides (Beyries et al. 2001). It also is possible that the unpredictability of situations requiring scraper use leads individuals to curate a variety of scrapers with different functional properties in anticipation of these needs.

Some aspects of lithic raw material economy observed among Australian aboriginal groups also may stem from the embeddedness of stone acquisition in their more mobile past (e.g., the manufacture and curation of men's knives, adzes, and other tools). Unfortunately, much of the observed stone tool manufacture in this region was staged, where knapping occurred when raw material was specially acquired for this purpose using modern transport technology (Binford 1986; Binford and O'Connell 1984; Gould et al. 1971; Hayden 1979). Unsurprisingly, knapping at residential centers with abundant stone tends to resemble the cases of expedient flake manufacture and use already discussed for other sedentary groups (especially Hayden's 1979 description of this phenomenon). Binford (1986) also describes a case in which a core was transported from a quarry to a residential center using his pickup truck and a series of expedient flakes was produced. Subsequently, flakes were selected for certain tasks or retouched into various "formal" tools. In this case, raw material was not abundant, but the expedient flake pattern was nonetheless manifest.

In Binford and O'Connell's (1984) account of knapping at a quarry, certain aspects of behavior no doubt resulted from strategies designed to deal with raw material transport, such as the extensive testing and early-stage reduction of a core at the quarry and the transport of a relatively small number of blanks with the desired properties for making men's knives. This was not, strictly speaking, expedient knapping, as it was directed at making a range of predesigned products to become elements of transported toolkits. However, even with these technical goals in mind, the process of knapping was very much one of ad hoc selection of flakes with certain desired qualities for subsequent tool manufacture (Fig. 3). The Alyawara case studies, if nothing else, demonstrate that the abundance or scarcity of raw material is not the only or inevitably the primary influence on knapping strategies. Instead, it is the anticipation of future needs and the organization of activities to assure the presence of necessary tools that determine knapping strategies. This includes both the production of formal tools as elements of personal toolkits and the transport of cores intended for expedient knapping at residential centers.

In some senses, the relationship between lithic raw material availability and knapping strategies in the ethnoarchaeological record presents a frustrating contradiction. Cases characterized by the presence of locally available, adequate-quality stone fit a pattern astutely recognized by Parry and Kelly (1987) some time ago. There also are cases in which raw material is specially sought out with relatively high costs. In these cases, raw material economy seems to be much less of a factor influencing knapping strategies than other considerations such as the specificity of tasks carried out with the resulting tools. In addition, there is at least one clear case in which expedient knapping occurred with transported lithic raw material, with little apparent concern for economizing or conservation.

My point is not to deny the central role of raw material economy in determining knapping strategies. Many well-known aspects of the archaeological record demonstrate that raw material economy strongly influenced both the technology and the spatial distribution of stone tools (Andrefsky 1994, 2009; Ashton and White 2003; Bamforth 1991; Bamforth and Becker 2000; Brantingham 2003; Jelinek 1977; Kelly 1988; Kelly and Todd 1988; Kuhn 1991, 1995; MacDonald 2009; McCall 2007; Odell 1996; Parry and Kelly 1987; Torrence 1983). Yet a number of these ethnoarchaeological cases suggest that raw material economy is only one dimension of the technological considerations that influence knapping behavior. The organizational conditions of tool manufacture also influence knapping strategies. Likewise, concerns for raw material economy during knapping episodes result from such organizational circumstances.

Planning, scheduling, and the organizational properties of tool systems

The organizational perspective is particularly helpful in thinking about expedient flake use in ethnoarchaeological situations. Parry and Kelly (1987) are correct that raw material abundance figures in the explanation of this phenomenon according to their observation: If raw material is limitless, why invest energy in elaborate knapping strategies when a sharp flake will do? On the other hand, it also is clear that raw material is not always so limitless and actually may represent a noticeable expense in terms of acquisition and opportunity cost.

Planning and the redundancy of the circumstances of knapping and stone tool use go further in explaining this phenomenon. In the village agricultural cases, the locations of raw material collection, knapping, and stone tool use are clustered, usually near residential units. In addition, the tasks for which stone tools are used are extremely redundant—generally the manufacture of wooden components of other tools. Even when used for other types of tasks, such as animal butchery, this activity usually occurs within a very narrow range of circumstances, which recur with a high degree of regularity and predictability. Raw material collection is incorporated into other everyday economic activities (i.e., tending agricultural fields), and expedient knapping may be relied on as a solution to a redundant set of technical problems and conditions. Raw material availability is an important precondition, yet planning and the redundancy of tasks go further in explaining the pattern of expedient knapping. Although expedient knapping is frequently linked with "situational" tool use [as defined by Binford (1979)], these cases are not situational in a strict sense of that term.

The three cases of stone scraper use also benefit from the organizational approach. While formally similar in a number of superficial characteristics, the cases of Gamo, Konso, and Chukchi hide scraping are quite different from one another in terms of technological organization. Gamo hide-scraping workshops combine all of the raw materials necessary for constructing hide-scraping tools, including lithic raw material, handles, mastic, and the components for their manufacture and repair. Once again, the location of technical activities and the presence of necessary raw materials are redundant and may be relied on consistently. Thus scrapers are retouched in predictable ways through a continuum of reduction stages (Shott and Weedman 2007) and are systematically discarded in high frequencies with regular characteristics.

For the Chukchi, hide scraping is an ongoing activity that must be scheduled during movement around the landscape. The presence of various requisite raw materials may not be relied on but is contingent on the location of camps and associated economic activities. Thus the Chukchi carry a range of relatively specialized scraper types necessary for all phases of hide scraping. Leaving aside the presence of other raw materials (e.g., tanning agents), scraper handles and scrapers are curated. Clearly, the archaeological record of scraper manufacture among the Chukchi is fundamentally different from that of the Gamo and Konso because of major differences in the organizational properties of technological systems. Even though the same basic task is being done, the specifics of context, scheduling, and planning bring about major differences in the characteristics of the resulting archaeological record.

Finally, the case of Turkish threshing-sledge manufacture represents an altogether different pattern of technological organization. In this case, stone was systematically mined, specialists knapped it into tightly constrained end products, and it was sold at market to consumers. This has more in common with an automobile assembly line than it does with the Paleolithic. Yet it is an interesting case because it requires the coordination of a number of independent activities by craftspeople with differing skill sets. It also results in an archaeological record of highly similar discarded waste products, which are spatially clustered. This case has a great deal in common with Mesoamerican prismatic blade manufacture in terms of organizational characteristics (Healan et al. 1983), and it may be productive to consider the broader economic circumstances that supported it.

Numerous lithic ethnoarchaeologists have warned us that the "usual suspects" of subsistence economy, tool function, and raw material economy fail to satisfactorily explain observed variability (Arthur 2010; Gallagher 1977; Gould 1980b; Gould et al. 1971; Weedman 2000, 2002, 2006; White 1967; White and Thomas 1972), and this claim seems to have some validity. What is missing, I would argue, are the comparative insights offered by the organizational approach. When we blur our vision, the tasks people accomplish with stone tools and the ways in which lithic raw materials may be collected start to seem broadly similar. However, the conditions under which these activities are done, their predictability, their scheduling, their degree of redundancy, and their intensity are all highly variable. These conditions strongly affect both knapping strategies and the spatial/temporal organization of technological activities. Thus they have a profound impact on the formation of the archaeological record of stone tools in complex ways.

Afterthoughts on style and social context

There are several instances in the ethnoarchaeological record where stone tools are basically nonfunctional items that have prestige value. The manufacture of groundstone adzes in highland New Guinea is one such case (Hampton 1999; Petrequin and Petrequin 1993; Stout 2002). Ethnoarchaeological studies there have not focused on the functional properties of tools, which are ground into their final form and are not used with great frequency. Stout (2002), for example, was interested in the social contexts of learning to knap large bifacial tools that have broad formal similarities with the Acheulean handaxe. In this case, the skill sets of craft specialist knappers are organized largely along the lines of aesthetics (Hampton 1999; Petrequin and Petrequin 1993; Stout 2002). Aesthetically pleasing adzes are more valuable. This becomes the primary goal of adze design and knapping practices, with aesthetic beauty the currency that New Guinea adze knappers seek to optimize.

Modern American knappers also are almost exclusively interested in aesthetics (Whittaker 2004). They go to great lengths to produce the large bifacial projectile points typical of the early prehistory of North America. Knappers derive prestige from their peers for producing tools with a combination of features demonstrating their skill. These include size, thinness, and pattern of flake scarring. While there are cases of knappers using their tools for functional purposes [e.g., Flenniken and Raymond (1986) hunting deer with stone projectile points or Crabtree having heart surgery performed with obsidian blades], these are quite exceptional. As Whittaker (2004) describes, most knappers would be unwilling to part with their "good points" for such short-term purposes. Once again, aesthetic qualities form the knapping strategies at work and the value of resulting products.

These cases illustrate a presumed theoretical dichotomy between function and aesthetics. It has long been the practice of archaeology to deal with aesthetics or "style" as everything leftover once the strict function of an object has been controlled for (Barton 1997; Collard et al. 2005; Dunnell 1978; Hodder 1977; O'Brien et al. 2001; Sacket 1982). However, studies such as Wiessner's (1983) work on Kalahari San projectile points demonstrate that aesthetics and style may form an important element of tool design in terms of the transmission of information (see also Wobst 1977). Likewise, Australian Kimberly points are another good example of an artifact type whose formal properties act as elements of assertive style within a process of weapon exchange (Akerman et al. 2002). This assertive sense of the term "style" implies the resolution of a technical problem in the same way as any other technology. The problem in this case is the transmission of personal information or status through various formal characteristics of artifacts (Wiessner 1983; Wobst 1977).

The case of Gamo scraper use illustrates alternative aspects of the information-transmission sense of the term "style." The Gamo use two variants of stone stone scrapers and handle forms: A relatively "formal" scraper fitted into the *zucano* handle and a relatively "informal" scraper fitted into the *tutuma* handle. Weedman (2006) argues that Gamo use both types of scraper handles by virtue of being at the border of two ethnic zones in which either *zucano* or *tutuma* handle types are used. She finds that individuals are signaling a certain line of paternal ancestry (with attached clan and caste information) by using a certain handle design. This is more like the concept of emblemic style recognized in Wiessner's (1983) study, and Weedman (2006) makes an argument couched in the tenets of agency and practice theory to explain it.

The situation is reminiscent of the debate between Gould and Binford concerning Australian lithic raw material procurement (Binford 1985; Binford and Stone 1985; Gould 1978, 1980a, 1985; Gould and Saggers 1985). In his original analysis of lithics from the Puntatjarpa rock shelter, Gould (1978, 1980a) found a surprisingly high frequency of adzes made from exotic lithic raw material of putatively inferior quality compared with local stone. He employed this fact in support of a claim that symbolic systems—specifically the manifestation of connections with points on the landscape through exotic raw material use—drove the collection of inferior-quality exotic raw materials. In proposing an organizational viewpoint on this problem, Binford (1985; Binford and Stone 1985) argued that high frequencies of exotic lithic raw materials resulted from the dynamics of movement around the landscape and the transport of tools from certain raw material sources to distant residential contexts.

What these cases have in common is the approach of eliminating functional variables (i.e., tool efficiency, raw material availability, raw material quality, etc.) as a way of supporting an ideational explanation of lithic assemblage characteristics (Gould 1978, 1980a, 1985; Weedman 2000, 2006). This is basically the view of style as everything leftover when functional considerations are held constant. In both cases, ideational factors may play a role in influencing the characteristics of lithic assemblages. Yet it is difficult to form referential frameworks with which to approach the archaeological record with this view of style, as the actual relationships between lithic assemblage characteristics and the variables that influence them remain opaque. Instead, these cases reduce to cautionary tales in which nonutilitarian variables (typically ignored by materialist archaeologists) play a primary role in lithic assemblage formation.

As Wiessner (1983) demonstrated for projectile points, the information exchange view of style sees aspects of tool design as intended for sending messages (see also Wobst 1977). Ethnoarchaeological identification of the individuals or groups intending to send signals, the signals they intend to send, and the manifestation of those messages in terms of the formal characteristics of artifacts represents a strong referential framework for studying style in the archaeological record. At the same time, archaeological stone tools are often the subject of stylistic studies because of their antiquity and durability relative to more appropriate classes of artifacts (e.g., ceramics or symbolic objects made from perishable materials). In comparison with the vast quantity of stone tool debris deposited into the archaeological record, the range of stone tools plausibly encoded with such forms of information would seem to be very narrow indeed.

Summary and synthesis

There are some apparent categories of stone tool manufacture and use that seem relevant for the construction of archaeological frames of reference. Although admittedly broad, these categories represent useful consistencies in terms of the formal characteristics of stone tool assemblages and various economic practices, specific technical problems, design strategies, stone tool functions, raw material economies, and organization properties of technological systems. These consistent relationships, though somewhat limited in their contextual breadth, are the kind of methodological uniformities necessary for constructing referential frameworks.

Many cases are characterized by the production of informal tools through expedient flaking carried out in villages, residential units, or attached activity areas. They are typified by the (over)production of flakes followed by a process of experimentation with the results for the resolution of immediate technical problems. These cases rely on the local availability of adequate-quality lithic raw material. They also have predictability in terms of the scheduling and location of tasks requiring stone tools and the presence of all necessary raw materials. This category includes the majority of the cases reviewed in this paper.

Other cases are characterized by the production of tools requiring more elaborate manufacture sequences with specialized formal properties. Within this category there is great variability: some cases are characterized by the relatively expedient production and discard of tools used for intensive processing of some resource (e.g., Gamo and Konso scrapers). Some cases show the curation of specialized tools for long periods of time (e.g., Chukchi scrapers). Some cases include the manufacture of curated tools intended to be multifunctional in their use and requiring significant effort in manufacture (e.g., Australian men's knives). Finally, some cases are characterized by the manufacture of nonfunctional items for largely symbolic purposes (e.g., New Guinea adze manufacture and modern American knappers).

This comparative analysis illustrates that raw material availability alone does not account for all of the properties of expedient core reduction. These tasks are fairly diverse in terms of the technical demands they place on stone tools, and expedient flakes offer cheap versatility in addressing these demands. More importantly perhaps, these cases have organizational characteristics in common in terms of the timing and location of tool manufacture and use. In addition, they share the reliable presence of all required raw materials. Included tasks, such as the manufacture of components of other tools, are not time-sensitive; they require repetitive technical sequences, and they recur predictably in the same places and times. While adequate-quality stone is a perhaps a prerequisite, other organizational factors are powerful determinates of expedient knapping.

Closer relationships between form and function, in part, drive the design of retouched tools. For example, the manufacture of scrapers relates to fairly specific sets of functional demands (Beyries and Rots 2008). Design specificity also seems to drive the acquisition of stone from relatively distant or otherwise expensive sources. It is clear, however, that organizational dynamics play a crucial part in structuring patterns of the manufacture, use, and discard of formal tools. In this respect, there seems to be a division within the second category: one common pattern is the production of formally redundant tools in workshops and in the context of craft production. Gamo and Konso scrapers, Turkish threshing-sledge blades, New Guinea adzes, and even modern American biface knapping all share this characteristic. The other pattern is the intentional manufacture of curated items for the resolution of anticipated future needs—Binford's (1979) "personal gear." In these cases, mobility creates circumstances in which the presence lithic raw material is not reliable, the conditions of technological activities are not redundant, and their scheduling is less predictable. These organizational factors related to mobility bring about the observed patterns of tool design and curation.

Many of the lithic ethnoarchaeological cases I have reviewed may be characterized individually as cautionary tales, warning against the primacy of frequently cited variables in explaining the characteristics of archaeological lithic assemblages. My review confirms that no specific case can be adequately explained by any single variable, utilitarian or otherwise. It also demonstrates that an understanding of technological organization, grounded in a comparative perspective, has the potential to see the relationships between the various causes of lithic assemblage characteristics. Furthermore, it recognizes the strategic aspects of technology in addressing both immediate and anticipated problems, as well as the spatial segregation of technological activities as the cause of assemblage characteristics. Thus an organizational view of lithic ethnoarchaeology based on a comparative approach may identify methodological uniformities that underpin productive archaeological frames of reference.

Learning about the technological properties of stone tools—present and past

The ethnoarchaeological cases that I have presented employ disparate theoretical concerns, methodological approaches, and analytical practices, making it difficult to construct cross-cultural comparisons necessary for the contextualization and explanation of variation. Indeed, few of these studies were done with comparative goals in mind, despite the success of certain lines of comparative research (e.g., Parry and Kelly 1987). Yet if the ethnoarchaeology of stone tools is to move beyond cautionary tales or substantive analogies, then the direction of research must shift to facilitate comparative approaches focused on the documentation of cross-cultural variation. This requires a transition to the adoption of more congruent methodological strategies and analytical approaches—if not theoretical interests.

Even ethnoarchaeological studies aimed at understanding what might be viewed as cognitive problems could benefit from a documentation of technological organization. In New Guinea, Stout (2002) documents the learning of skills necessary for knapping large bifaces similar to those found in the Acheulean archaeological record. On the one hand, his arguments about the qualities of knapping skills and the necessity of certain kinds of social interaction to learn them are clearly valid. On the other hand, to what degree are the dynamics of teaching and learning influenced by their context in a craft workshop in which raw materials and tools of production are always combined predictably? Does it matter that knappers are learning to make a single kind of object with highly redundant properties? It is doubtful that these questions have much to do with the cognitive hardware required for learning (which, in fairness, is probably Stout's main point), but the organizational conditions of adze production clearly influence the social dynamics of learning. They warrant specific attention, even if social structures of teaching and learning are the main theoretical focus.

Technological analytical perspectives offer a common vocabulary and a set of analytical principles with which to think systematically beyond single cases and build comparative frameworks. They also offer a referential basis for explaining the properties of lithic assemblages in terms of the cultural dynamics that create them. More than this, however, the organizational approach helps identify the ways in which the specific contexts of technological activities influence and constrain the manufacture and use of tools. This includes aspects of social behavior, such as the learning of skills and tool decoration for the purposes of signaling, which are traditionally separated from studies of technology as ideational concerns.

There also are aspects of the lithic ethnoarchaeological record that may help clarify ambiguous concepts within the organizational approach and provide referential contexts for the analytical units of the chaîne opératoire and the sequence of reduction perspectives. Archaeological studies of stone tools fundamentally involve the characterization of assemblages originating from some discrete spatial/temporal unit (i.e., the stone tools from one site or a contained stratigraphic unit). Design theory is a referential framework linking the formal properties of specific tools with certain kinds of technological strategies, various technical problems, and functional demands. The organizational approach focuses on the formation of archaeological assemblages with characteristics stemming from the spatial segregation of certain kinds of technological activities and the broader strategic concerns that bring these about. Combined, the design theory and organizational approaches offer an inferential framework for relating the formal characteristics of discrete assemblages with the broader properties of cultural systems that produced them. Whereas design theory and the organizational approach were largely based on studies of nonlithic technology, a comparative approach to lithic ethnoarchaeology can elucidate technological dynamics specific to stone tools.

For example, there is a wide range of lithic ethnoarchaeological information with which to address the much-contested concept of curation and to work toward an operational definition applicable to the archaeological record (Shott and Sillitoe 2005; Shott and Weedman 2007). Stemming from difficulties in both defining and recognizing curated stone tools in the archaeological record, a number of lithic analysts have employed various retouch indices for scrapers and bifaces as proxies for curation (Andrefsky 2006, 2009; Blades 2003; Clarkson 2002; Clarkson and Hiscock 2008; Dibble 1995; Eren and Prendergast 2008; Eren and Sampson 2009; Eren et al. 2005; Hiscock and Attenbrow 2003; Hiscock and Clarkson 2009; Horowitz 2010; Kuhn 1990; Shott 1996; Shott and Ballenger 2007). This also has been the subject of significant lithic ethnoarchaeological research (Shott and Sillitoe 2005; Shott and Weedman 2007; Weedman 2002). Yet there are important questions about the quantification of stone tool curation.

Comparison of the Gamo, Konso, and Chukchi cases illustrates important methodological concerns in dealing with the curation concept as it pertains to scraper retouch. Gamo and Konso scrapers are intensively retouched before their discard and would register high values of retouch (and therefore curation) according to the various indices outlined above (Shott and Weedman 2007). Yet they are produced with relatively little effort (excluding raw material collection), they are used for a single task, and they are discarded after a matter of hours. Such objects certainly do not fit the original intent of the curation concept (Binford 1979), but they do score highly on the continuous measures of curation based on degree of retouch. In contrast, the Chukchi keep a number of scrapers at different stages of retouch for hide-scraping activities of differing intensity. The retouch indices of curation would recognize them as quite different from one another. Yet, in terms of the original concept, they are all equally curated. Furthermore, the curation of Chukchi scrapers points to important aspects of technological organization and a strategy stemming from patterns of residential mobility and the economic demands of herding reindeer in the Artic.

Beyond acting as a cautionary tale, this contrast has methodological implications concerning the quantification of tool curation. Beyond retouch indices, how do we recognize curated stone tools in the archaeological record? How might we recognize such different patterns of curation when the basic formal characteristics of scrapers are similar? I suggest that consideration of whole assemblages and isolation of the relationships between artifacts is necessary to diagnose the curation of certain stone tools effectively. In the Gamo and Konso cases, lithic assemblages result from the discard of workshop refuse, combining all stages of knapping debris involved in scraper manufacture and reduction. In the Chukchi case, discarded scrapers often occur in the absence of much other knapping debris, distant from their location of initial manufacture and raw material source. The relationship of scrapers with the characteristics of the assemblages in which they are found is what offers real information about patterns of curation.

This is not to devalue retouch indices as methods for addressing issues of tool reduction, use life, raw material economy, and related issues of mobility. Within specific culture-historical contexts, where basic tool designs and reduction patterns are known a priori, such indices give us great insight concerning how the extent of tool retouch relates to raw material transport and, therefore, mobility. For example, the reduction sequences of North American projectile points has long been studied (e.g., Holmes 1894) and is well understood in both regional and temporal terms. Therefore, the degree to which a certain type of point has been reduced is meaningful because it can be contextualized in terms of (presumably) known reduction sequences. In such cases, knowledge of spatial/temporal context facilitates the use of retouch indices, as specific artifact forms and broader archaeological patterns are understood ahead of time. There also are many studies that do, in fact, relate reduction indices to other assemblage characteristics and inferred aspects of core reduction strategy (Blades 2003; Dibble 1995; Hiscock and Attenbrow 2006; Kuhn 1991, 1995; Shott and Sillitoe 2005). My point is simply that the degree to which a scraper or biface has been retouched from its original form is not, per se, a quantification of curation that can be linked with technological strategies and organizational dynamics with complete clarity.

Lithic ethnoarchaeology has implications for the concept of expediency as well. A number of anecdotal accounts of expedient flake use have served as important talking points for advocates of the organizational approach. Perhaps the most famous of these is Binford's (1979, p. 266) example from the Nunamiut in which a hunter lost his good knife in a lake during a hunt and butchered his kill by making expedient flakes from local stone. In Binford's terminology, this is "situational gear" characterized by expediency. Although there are other influential stories of similar technological behavior (e.g., Stow's 1905 description of San expedient flaking in the Western Cape region of South Africa), this important organizational category remains underexplored with actualistic data.

Throughout this review, most of the observed expedient flake use is not situational but rather a planned coalescence of tasks in need of resolution, with lithic raw material needed for producing flakes. Instead of acting like situational gear, it is actually more akin to "site furniture" (Binford 1979; see also Deal and Hayden 1987, who view this as a type of curation). Whereas knapping at raw material sources is a separate issue, expedient knapping in residential contexts inherently involves the planned provisioning of the locations of technological activities with lithic raw materials and flake debris. It is clear that tools such as Ethiopian hide scrapers and Australian men's knives illustrate the same pitfalls, while using the absence of retouch as an index of expediency for opposite reasons.

In addition to these implications for the organizational approach, technological analytical methods, such as the chaîne opératoire and sequence of reduction approaches, have a great deal to gain from ethnoarchaeological studies of stone tools. In a recent review, Bar-Yosef and van Peer (2009) raise a number of important concerns for the chaîne opératoire perspective that revolve around overly rigid typological categories for technological products at various putative stages of operational sequences. They also point out problems with interobserver reliability and react against the view that the chaîne opératoire can offer any real information about knapper decision making or, more generally, what was on the minds of prehistoric people (Andrefsky 2009; Shott 2003; cf. de la Torre and Mora 2008; Sellet 1993). Rinehart (2008) voices a similar concern with the sequence of reduction approach, arguing that the identification of debitage reduction stages is often arbitrary and separated from our broader analytical goals.

The potential value of the documentation of the operational sequences involved in core reduction and/or tool production provided by the chaîne opératoire and the sequence of reduction is evident for the organizational approach (Sellet 1993). Yet, to this point, experimental knapping has provided the sole basis for linking debitage with its sequential position and the reconstruction of manufacture strategies from operational sequences. Lithic ethnoarchaeology offers us the chance to test our assumptions concerning how operational sequences actually relate to broader technological strategies and to more efficiently focus our attention on the aspects of operational sequences that most directly relate to technological organization.

Perhaps the longest-term research project conducted within the chaîne opératoire framework is the analysis of the French Magdalenian sister sites of Pincevent and Verberie, beginning with the efforts of Leroi-Gourhan and Brézillon (1972). The lithics from both sites have been extensively refitted, and the operational sequences for individual cores are known in great detail (Bodu 1996; Keeley 1987). It is currently believed that Pincevent was a long-term residential base, whereas Verberie is thought to have been a logistical hunting camp positioned along a reindeer migration route (Enloe 2006).

The extensive refitting at Pincevent has demonstrated that blades were overproduced as a technological strategy. Blade cores refit at nearly complete levels and are missing only the highest-quality blades. Use-wear studies have shown the use of blade debitage for a wide range of technical tasks, especially the manufacture of bone and antler tools (Audouze et al. 1981). Verberie's lithic assemblage is broadly similar, but there are a few noteworthy differences. Its assemblage is smaller, its refitting sequences show fewer core reduction episodes, and the refitting rate at the site is lower (Audouze et al. 1981; Keeley 1987). Use-wear studies show a relatively high frequency of discarded backed tools, with wear resulting from hafting, representing the discarded components of composite tools (Symens 1986). Such studies also show that unmodified blades were frequently used for animal butchery.

Technological analytical perspectives based on ethnoarchaeological research allow construction of significant inferences on the basis of these chaînes opératoire. The missing blades at Pincevent were likely modular components of curated tools and hunting weapons. Use-wear information and the debris from working bone and antler point to the construction of compound tools with backed blade components. In addition, it may be inferred that the knapping at Verberie was aimed at retooling (Keeley 1987) and also as a source of flakes for the initial field butchery of reindeer killed near the logistical campsite (Enloe 2006; Symens 1986). Thus an overarching technological strategy may be recognized, with site-specific organizational differences stemming from the dynamics of site function.

In certain respects, the patterns of knapping at Pincevent and Verberie are quite reminiscent of the Alyawara case studies (Binford 1986; Binford and O'Connell 1984). Cores were reduced and resulting debitage either modified for inclusion in personal toolkits or used expediently in solving immediate technical problems. This ethnoarchaeological information offers insights concerning the organization of Magdalenian technology, and these lithic analyses support views of site function based largely on faunal remains (Enloe 2006). Taken as a whole, these studies point to reliability as a principle of weapon design in the context of a highly specialized reindeer hunting strategy. They also support the view that Magdalenian foragers employed a logistically oriented mobility pattern designed specifically to target resources clumped in both space and time.

The stone tool research at Pincevent and Verberie clearly demonstrates the value of chaîne opératoire analytical methods, especially refitting. It also illustrates the necessity of strong referential frameworks for making sense of such complicated and varied data. The organizational approach, informed with lithic ethnoarchaeological research, provides a basis for examining both the design of composite weapons and the planned expedient exploitation of unmodified blade debitage for various technical purposes.

Case study: An organizational approach to Acheulean handaxes

Acheulean handaxes were at the heart of early Paleolithic archaeological studies, demonstrating the deep antiquity of humankind (Boucher de Perthes 1847). They have continued to receive attention by virtue of their striking formal characteristics and archaeological patterning. There has been a surge in the scholarship on handaxes in the last decade (Grosman et al. 2008; Kohn and Mithen 1999; McCall and Whittaker 2007; McNabb et al. 2004; McPherron 2000; Nowell and Chang 2009; Roberts and Parfitt 1999; Stout 2002; Whittaker and McCall 2001), and handaxes also have been the subject of the organizational approach (Ashton and White 2003; Binford 1987).

Most studies have focused on the formal characteristics of handaxes themselves (i.e., size, shape, thinness, symmetry, and the functional implications of these characteristics; see Isaac 1977). Recent examples have involved innovative and technologically sophisticated approaches to geometric morphometrics (Archer and Braun 2010; Grosman et al. 2008). However, some of the most interesting aspects of the handaxe phenomenon have more to do with the formal characteristics of handaxes themselves than with the characteristics of assemblage composition and context (Binford 1987; Isaac 1977; McCall and Whittaker 2007; McNabb et al. 2004; Nowell and Chang 2009).

One such aspect of patterning is the tendency for contemporaneous and geographically proximate sites to have either extremely dense concentrations of handaxes or a lack of them almost entirely. In Europe, Boxgrove and Clacton are good examples of this phenomenon. Though broadly similar in age, Boxgrove has many handaxes (Roberts and Parfitt 1999), whereas Clacton famously lacks them—serving as the type site for the non-handaxe "Clactonian" industry (Ashton et al. 1994). In Africa, there are sites such as Olorgesailie (Isaac 1977) that have vast concentrations of handaxes, while contemporaneous assemblages have very small numbers or lack them entirely (Clark 1970; Leakey 1971; Sampson 1974; Schick and Toth 1993). Although there were early attempts to explain this phenomenon in chronological or culture-historical terms (the Clactonian and Developed Oldowan industries), it is now recognized that the contrast between these two types of assemblages probably represents two sides of the same coin.

This general pattern can be illustrated in greater detail with archaeological data. In his seminal monograph, Isaac (1977) offers data for 19 localities at Olorgesailie, a well-studied set of Acheulean sites in Kenya dating to around 700,000 years ago. Isaac presents the assemblage frequencies for a range of typological categories based on reduction sequence; thus they are like most lithic data sets in their characterization of assemblages. These typological categories include various forms of handaxes, cores, retouched flake tools, and unmodified flakes. In reducing these data, I performed a principal components analysis (PCA), a statistical tool for recognizing packages of correlated types of artifacts, which effectively represent latent variables (see McCall 2007 for further discussion). This PCA isolated six components with eigenvalues greater than 1 (Table 2).

These statistical findings illustrate the dichotomy between sites with and without handaxes and point to other interesting aspects of archaeological patterning. Table 3

Table 2 Principal components loading scores for Olorgesailie stone tool typological data

Rotated component matrix[a]	Component					
	1	2	3	4	5	6
"Classic" handaxes	.086	.142	**.771**	−.301	.216	−.026
Pick handaxes	**.978**	.033	.025	.001	.061	.007
Chisel handaxes	−.037	−.104	.100	−.097	**.906**	−.243
Cleavers	**.980**	−.033	.041	.112	−.006	.039
Knives	**.967**	.051	.056	−.027	−.018	.047
Picks	**.880**	.236	.214	−.096	−.118	−.065
Broken handaxes	.302	.112	−.167	.092	**.808**	.327
Choppers	**.821**	.358	.221	.204	−.070	.010
Regular cores	**.547**	**.713**	.000	.217	−.024	−.220
Irregular cores	**.771**	.414	.164	.354	−.131	−.092
Casual cores	**.697**	**.638**	.129	.035	−.073	−.235
Core scrapers	.374	.451	−.340	**.569**	−.005	−.097
Core fragments	**.608**	.396	−.206	−.220	.113	.453
Large flake scrapers	**.966**	.194	−.037	−.028	.097	.013
Core bifaces	−.100	**.776**	.365	−.049	.186	−.315
Other large tools	**.798**	.273	−.055	−.089	.131	.143
Small simple scrapers	.011	**.956**	.049	−.061	.101	−.014
Small nosed/pointed tools	.099	**.845**	−.190	.072	−.093	.133
Other small tools	−.164	−.201	.139	**.915**	−.030	.092
Spheroids	**.674**	.103	.251	.415	.069	.215
Large trimmed flakes	**.887**	−.015	−.039	−.092	.303	.000
Small trimmed flakes	.403	**.778**	.193	−.104	−.073	.254
Broken large trimmed	**.902**	.028	−.137	−.116	.023	.044
Broken small trimmed	.300	**.782**	.322	−.189	−.118	−.214
Large flakes	.070	−.370	.392	.202	−.081	**.626**
Small flakes	−.044	.070	**.896**	.181	−.221	.087
Very small flakes	.165	.288	**.866**	.078	−.000	−.225
Flake fragments	.036	−.086	**.850**	.081	.001	.212

[a] Rotation method: Varimax with Kaiser normalization; rotation converged in eight iterations

Table 3 List of variable clusters derived from principal components analysis of Olorgesailie stone tool typological data

Principal Component 1
Pick handaxes
Picks
Cleavers
Knives
Choppers
Regular cores
Irregular cores
Casual cores
Core fragments
Large flake scrapers
Large trimmed flakes
Broken large trimmed flakes
Spheroids
Other large tools
Principal Component 2
Regular cores
Casual cores
Core bifaces
Small simple scrapers
Small-nosed and pointed tools
Small trimmed flakes
Broken small trimmed flakes
Principal Component 3
"Classic" handaxes
Small flakes
Very small flakes
Flake fragments
Principal Component 4
Core scrapers
Other small tools
Principal Component 5
Chisel handaxes
Broken handaxes
Principal Component 6
Large flakes

lists the six clusters of stone tool types derived from the PCA. This patterning is broadly consistent with many prior characterizations of the Acheulean handaxe phenomenon. PC 1 represents handaxe-dominated sites and PC 2 represents the non-handaxe/small-tool sites of the type proposed by Binford (1987) and typical of the Developed Oldowan (Clark 1970; Leakey 1971; Schick and Toth 1993). Although the composition of these components might be expected in terms of previous descriptions of the Acheulean, both are aspects of the same set of archaeological contexts at Olorgesailie.

The stone tool types that populate PC 3 offer further information concerning the handaxe/non-handaxe site phenomenon. This component contains the most general form of biface, seen by Isaac (1977) as the root of the reduced handaxe forms that load on PC 1. Similarly, McPherron (2000) makes the point that the PC 1-derived handaxe forms result from the intensity of retouch/extent of tool reduction rather than from aspects of intentional design. One possibility is that the PC 3 sites represent the locations of handaxe manufacture and that PC 1 sites represent handaxe (and other core) transport and their entry into the archaeological record as intensively reduced forms and more exhausted cores. From an organization perspective, the differences between these two types of sites may result from their location on the landscape (e.g., high frequencies of debitage and generalized handaxes at quarry sites) and the curation/transport of handaxes, cores, and other tool forms.

The stone tool types associated with PC 2 are typical of the small-tool end of the big-tool/small-tool divide described by Binford (1987) and, more generally, of the Developed Oldowan industry in East Africa. The characteristics of PC 2 sites also seem to have resulted from the curation/transport of certain retouched tool and core types, but not handaxes. This shows that small-tool sites are actually just one variety of non-handaxe sites. Such sites may represent the location of tool transport but perhaps with different functional properties associated with different sets of activities from the PC 1 sites. In addition, if it is accepted that handaxes were, at least in part, a core reduction strategy for the transport of lithic raw material across the landscape as cores (Jelinek 1977; Schick and Toth 1993), then PC 2 small-tool/non-handaxe sites may have resulted from their location relative to raw material sources, other important resources, and/or activity areas.

PC 4-PC 6 point to interesting phenomena but explain a relatively small amount of statistical variation and are not discussed further. The patterns represented by PC 1-PC 3, however, point to specific dynamics of handaxe manufacture, transport, and discard.

The first phase represents knapping activities at locations of abundant raw material supply, including early-stage core reduction, the roughing out of initial handaxe forms, and the situational use of expediently produced flakes for immediate activities. Initial handaxe forms were manufactured for transport to distant locations lacking lithic raw material. Non-handaxe cores were apparently tested and eventually transported, perhaps to different types of landscape location or with different intents. In addition, the debitage resulting from initial core reduction was used locally, and flakes with certain desirable properties were transported. Thus raw material source locations have assemblages populated with discarded "classic" handaxes and debitage, both associated with PC 3 in this study.

The second phase represents the reduction of handaxes/other core forms and the retouching of flake tools. Once distant from raw material sources, transported handaxes were reduced as they became dull and more flakes were removed from handaxes and other cores. Handaxes were transformed into their more derived forms, and cores were exhausted as they underwent these processes of reduction.

Flake tools also were retouched as they became dull, becoming the various formal tool forms. The reduced handaxe and core forms populate PC 1; retouched flake tools populate PC 2.

The third and final phase includes the discard of exhausted handaxes, cores, and retouched flakes at activity area sites. It seems likely that handaxes, cores, and flake tools were used and reduced primarily at these locations. This may explain the differences between PC 1 and PC 2 sites, which share high frequencies of reduced tool forms but are composed of different kinds of tools (i.e., the big-tool/small-tool divide).

Although not explicitly framed in its terminology, what Isaac (1977) offers in his description of tool size and shape variation is basically a chaîne opératoire or sequences of core reduction, handaxe reduction, and the retouch of flakes. What the organizational approach adds is an understanding of how these technical operations were distributed on the landscape (especially in terms of raw material supply) and how this spatial segregation of activities led to the formation of assemblages with differing characteristics. Lithic ethnoarchaeology enhances this information by demonstrating how the organizational properties of certain knapping strategies relate to other contextual variables.

For example, the expedient knapping at PC 3 sites shares its strategic characteristics with many cases of expedient knapping known from the ethnoarchaeological record. From an organizational perspective, expedient knapping points to the reliable combination of lithic raw materials and resources requiring processing and to predictability in the staging of technological activities. It also suggests that tasks requiring expedient flakes were not extremely time-sensitive, including the processing of locally available food items and/or the manufacture of other tools.

Lithic ethnoarchaeology also offers insights concerning the technological role of handaxes as curated items of personal gear. Handaxes require a greater investment of raw material, labor, and skill. Handaxes are found in reduced states at locations distant from their initial manufacture and in assemblages with little debitage, indicating curation and ongoing reduction as a technological strategy. The lithic ethnoarchaeological cases suggest that they were manufactured to be multifunctional and versatile to deal with unpredictable future circumstances, in terms of both the qualities of future activities and their location with respect to lithic raw material supply. Once again, it is not the formal characteristics of handaxes themselves or even the fact that they are bifaces that necessarily indicate their curation, rather it is the characteristics of assemblages in which they are found.

Thus an ethnoarchaeology of stone tools structured by the organizational approach offers a strong referential framework for approaching Isaac's (1977) data concerning the frequencies of objects from various operational categories. Lithic ethnoarchaeology and technological analytical perspectives help us see the "forest from the trees" in terms of Acheulean assemblage characteristics. As analytical techniques become more complicated (e.g., Archer and Braun 2010; Grosman et al. 2008), keeping this kind of perspective will only increase in importance.

Conclusion

The archaeological analysis of stone tools has increased in sophistication dramatically since the inception of the New Archaeology, owing significantly to the development of the organizational approach and allied technological analytical perspectives. I have argued that a comparative approach to lithic ethnoarchaeology can make substantial contributions to our understanding of technological organization, augmenting our knowledge derived from knapping experimentation and forager ethnoarchaeology. In addition, I have argued that lithic ethnoarchaeological research could maximize its impact on mainstream archaeological analyses by adopting a comparative approach based on organizational principles. Taken as a combined research program, such an approach could help clarify the definitions of important organizational concepts, such as curation and expediency, and elucidate their recognition in archaeological assemblages using technological analytical methodologies.

Since the inception of the discipline, archaeologists have struggled with the paradox that stone tools are the oldest, most durable, and most common type of artifact, but also perhaps the most difficult to understand. In developing learning strategies, archaeologists have reinvented a lost tradition of knapping and sought out the rare modern contexts in which stone tool use continues. While exceptional, modern cases of stone tool use are not simply flukes or curiosities, and they can act as more than a source of relevant anecdotes about lithic technology. Careful and systematic lithic ethnoarchaeological research can make significant contributions to our understanding of the organization of stone tool technology.

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