Measuring reduction in stone tools: an ethnoarchaeological study of Gamo hidescrapers from Ethiopia

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Abstract

Stone tools were knapped, not built. This truism means that tools were reduced from larger pieces in the production process. But many tools were further reduced in use, to repair damage or as edges dulled. Reduction reduced size (trivially), but also changed the proportions among tools' elements or dimensions. Such allometric variation (change in proportion as a function of change in size) is useful to estimate the degree of reduction that tools experienced. Reduction itself is a measure of curation, a theoretical concept of great interest in lithic studies and Paleolithic archaeology. To determine the reduction that archaeological tools experienced, we must compare their size and proportions at first use to the same properties at discard that we directly measure. By now many size estimates can be made from discarded tools. Some are experimentally tested but few are validated using direct ethnoarchaeological controls. We validate two allometric reduction measures—ratios of plan area to thickness and of an estimate of original to discarded volume—against direct measures of use and reduction in ethnographic Gamo hidescrapers from Ethiopia.

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1. Introduction

Their abundance makes stone tools one of archaeology’s most popular subjects. The range of lithic analysis befits such a common material, involving everything from source selection to use-wear to reveal the properties of ancient cultures and the details of ancient behavior. Perhaps the most common and one of the fundamental kinds of lithic analysis is simple typology, the act of assigning specimens to broad functional classes like "point" or "scraper" or to chronofunctional classes like "Kimberly point" or "Mississippian hoe blade."

Of course typology is a legitimate goal of lithic analysis. In recent years, however, many archaeologists have assimilated the reduction thesis, the understanding that retouched tools vary progressively from first use to discard by decrease in size and change in form depending on extent and pattern of the resharpening that they experience. Not all tools are retouched during use, so the reduction thesis is merely common, not universal. It is amply documented in many tool types from many times and places around the world (e.g., Andrefsky, 1997, 2006; Ballenger, 2001; Blades, 2003; Buchanan, 2006; Clarkson and Lamb, 2005; Dibble, 1995, 1997; Flenniken and Wilke, 1989; Granger, 1978; Grimes and Grimes, 1985; Hiscock, 1996; Hiscock and Attenbrow, 2005; Hoffman, 1985; Jefferies, 1990; Kuhn, 1990; Lerner, 2004; Potts, 1991; Sahnowi et al., 1997; Shott, 1995, in press; Shott and Ballenger, in press; Shott and Sillitoe, 2004; Truncer, 1990; Weedman, 2002b). It also is documented in ethnographic sources, mostly in unifaces for the simple reason that biface use is exceedingly rare in such accounts (e.g., Clark and Kurashina, 1981; Cooper, 1954; Gallagher, 1977; Haaland, 1987; Tindale,
are complex objects, some of whose geometric properties (e.g., Andrefsky, 2006; Clarkson et al., in press; Eren et al., 2005) require analysis to measure amount or degree of attrition that might be suitable for measuring reduction in many tool types. Yet few have been confirmed under controlled ethnographic conditions, where direct observation of reduction is possible. This paper details the pattern and degree by which chert and obsidian haidescrapers are reduced in an ethnographic assemblage. Its twin goals are to propose and validate reduction measures suitable for the tool type and to study the correlation between reduction and amount of work performed using stone tools.

2. Reduction analysis

Tool resharpening and the reduction that results complicate typological judgments, which may help explain the resistance that some exhibit to the reduction thesis. Complications are undeniable, but the thesis actually improves typological inferences both by minimizing the risk of creating false or chimerical types that arbitrarily parse continua of metric and formation variation, and by identifying legitimate typological classes that are not artifacts of reduction and its variation. But the reduction thesis delivers benefits beyond improved typological inferences.

For instance, patterns of reduction can implicate kinds of use by identifying the edges or segments of tools that were retouched. Degree of reduction is a measure of curation (Binford, 1973; Elston, 1992; Shott, 1996; Shott and Sillitoe, 2004), a theoretical quantity of considerable importance in lithic analysis. Although reduction is not equal to use life or longevity, reduction distributions permit archaeologists to calibrate discard rates of different tool types to common scales, and implicate different causes of discard. Distributions that reveal constant discard rate regardless of degree of curation suggest chance as the cause of discard while those that reveal discard rate increasing with curation implicate attrition (e.g., Shott and Sillitoe, 2004; Shott and Sillitoe, 2005). The reduction thesis is no mere complicating factor to typology, but a body of method and theory that considerably expands the scope of inference from stone tools.

Stone tools possess fundamental properties like size, form and weight, which change as reduction progresses. Some tools also possess distinct segments like blades, shoulders, and stems or haft elements, the proportional size of which change as reduction progresses. Change in proportions or shape with change in size is allometry. Reduction measures exploit these properties of stone tools and their changes that result from resharpening: some are based on simple measurement of size or weight, some are geometric, and some are allometric.

Simple size measures require knowing or estimating tools’ original size for comparison to their size at discard (Ahler, 1975). Such estimates are feasible for types that are highly standardized at first use, either by production technology or functional constraint. Cache specimens suggest that fluted bifaces, for example, are fairly standardized in original size, such that amount of reduction in used specimens of similar age and affinity can be estimated by simple comparison to average dimensions of cache specimens. But standardization of stone tools is imperfect, so this approach is limited. Technological attributes like plan form, cortex cover and dorsal faceting also can be used to gauge reduction (Weedman, 2000, p. 140).

Geometric reduction measures exploit systematic change in cross-section form of retouched tools. For instance, Kuhn’s (1990) “geometric index of unifacial reduction” is calculated as $t/T$, where $t$ is thickness of the retouched edge or bit (approximated as $D \cdot \sin(a)$ where $D$ is length of retouch scars and $a$ is angle of retouch) and $T$ is maximum thickness on the tool’s spine (Fig. 1). It assumes that flakes have triangular cross-sections, and that $t/T$ continually and monotonically varies because $t$ rises while $T$ is constant (and so also assumes that edges are not retouched sufficiently to reach $T$) (Dibble, 1995; Shott, 1995). Kuhn’s measure has been confirmed in part in Hiscock and Clarkson’s (2005) experiment (although $t/T$ did not pattern monotonically with amount of reduction, reaching its maximum value before reduction was completed) and has been applied to Middle Paleolithic European assemblages but especially to Holocene Australian ones (e.g., Clarkson and Lamb, 2005; Hiscock and Attenbrow, 2005). Unifaces include marginally and distally retouched tools (“sidescrapers” and “endscrapers,”respectively). In general, $t/T$ is suitable for sidescrapers but not necessarily for endscrapers, which often bear substantially parallel inferior and exterior faces. This is the “flat-flake” problem (Dibble, 1995; Shott, 2005), which is illustrated in experimental (Morrow, 1997) and possibly in archaeological data (fig. 14 in Kraft, 1973; Lerner, 2004, p. 7).

Geometric measures also include methods that divide tool surfaces into zones and then code each zone for a (usually) ordinal measure of retouch invasiveness (e.g., Andrefsky, in

![Fig. 1. Kuhn’s $t/T$ ratio calculated from tool cross-section: (a) before first use; (b) after retouch. Shading indicates segment of tool cross-section lost via resharpening.](image-url)
press; Clarkson, 2002). Apart from the occasional difficulty in distinguishing retouch from finishing flake scars, invasiveness measures seem somewhat laborious to apply (although users vouch for their efficiency; C. Clarkson, personal communication, 2005) and, like $i/T$, can reach a maximum value before reduction is completed. Hoffman (1985, pp. 581–583) suggested that edge angles of bifaces increased with resharpening. Wilmsen (1968, p. 159) suggested the same possibility for Paleoindian endscrapers but discounted it in favor of a functional interpretation by arguing that distinct edge-angle ranges reflected different functional tool types. Yet experiments showed that retouched edge angle did increase in endscrapers by resharpening (Giner and Sacchi, 1994, fig. 4; Morrow, 1997, table 4). Archaic (Jefferies, 1990, p. 9) and European Upper Paleolithic (Blades, 2003, pp. 147–148) data unevenly support the same conclusion. Accordingly, McMillan (2003, p. 63) measured endscraper reduction by edge angle, but also by bit concavity given as the ratio of bit width to its depth or length. Finally, Lerner (2004) defined geometric reduction measures that involved the ratio of two edge-angle measures.

Allometric methods rely upon the change in proportion between tool segments during use and reduction. For instance, blade segments of bifaces are reduced much more than are hafts (Andrefsky, 2006; Hoffman, 1985; Jefferies, 1990; Keeley, 1982; Shott and Ballenger, in press). Indeed, except for abrasive wear in use, repair, or opportunistic reuse, haft elements should not change at all during use. Relative to haft elements, therefore, size of blade segments should decrease steadily during use as they are retouched while hafts are not. But haft (and blade) segments can be difficult to identify, especially in unifaces, and size of blade segments is not necessarily standardized at first use. Hoffman’s (1985, pp. 582–584) measure, both geometric and allometric, related biface edge angle inversely to blade-segment area as a function of edge retouch (Fig. 2).

Dimensions like proximal thickness are both easy to measure and may remain constant during use, while dimensions like length constantly decline. Moreover, in unused specimens many dimensions are related to overall size, as shown by the high correlation that they typically show with general size measures like weight or volume (e.g., Kuhn, 1990, p. 240; Patten, 2005, p. 165). If dimensions like original length, width and thickness are correlated with size and if some among them like thickness change little or not at all during use while others like length change considerably, then ratios like length to thickness may register the changing allometry of tools as they are resharpened during use (Blades, 2003).

Size, geometry and allometry all measure degree of tool reduction. Among geometric approaches, invasiveness measures can also measure pattern of reduction. Archaeologists have devised a number of reduction measures of each kind and applied them to many assemblages. Experimental validations of proposed measures also have been conducted (e.g., Andrefsky, 2006; Hiscock and Clarkson, 2005). Given the range of lithic technologies and tool types, of course no one measure is adequate to them all. But to date, no reduction measure has been tested in a controlled ethnographic study where both amount of use and reduction are directly observed independently of reduction measures that archaeologists might use. Nor have the degree and pattern of correlation between reduction itself and amount of work performed by tools been determined in such controlled context. This study is designed as an initial attempt to fill both gaps, first by devising direct measures of reduction that depend upon ethnographic observation, then by devising indirect measures that can be computed from remnant dimensions of specimens as discarded for comparison to direct measures, and then by comparing all reduction measures to measures of work accomplished.

3. Reduction distributions

Once reduction is measured, archaeologists can compile reduction or curation distributions for tool assemblages (Shott, 1996). The scale (how much reduction) and form (the proportion of tools that experience different amounts of reduction) of such distributions are descriptive empirical properties of assemblages, but also measures of curation rate that implicate different factors that govern tool discard (Shott and Sillitoe, 2004; Shott and Sillitoe, 2005). Curation distributions can be compared between assemblages, but also analyzed individually. Depending on their forms and the distribution of values that comprise them, distributions fitted to the Weibull and other theoretical models may implicate the effects of chance versus attrition in tool failure (e.g., Shott and Sillitoe, 2004), with far-reaching implications for assemblage formation.

In North American Paleoindian assemblages, for instance, fluted bifaces and endscrapers have different characteristic cumulative-survivorship curves and failure distributions (Shott and Sillitoe, 2004) Biface discard is governed by chance, no surprise considering that bifaces (“points”) are thin for their size (Chesier and Kelly, 2006; Shott, 2002) and in use are subjected to many physical stresses from striking objects at high speeds. Endscraper discard is governed by attrition (although breakage is common in some assemblages (e.g., Seeman

![Fig. 2. Allometric relationship between declining blade size and rising edge angle in bifaces. Source: Hoffman (1985, fig. 18.7).](image-url)
et al., 1994, fig. 3), again no surprise considering that scrapers are thicker and more robust for their size and in use are subjected to fewer and less variable stresses (e.g., Ahler, 1975, p. 535). What amount to reduction distributions for varieties of Paleoeinidian endscrapers are reported in Grimes and Grimes (1985, figs. 6, 7) and Seeman et al. (1994, fig. 3); Ahler (1975, figs. N-5–N-7) provides late prehistoric hypothetical and empirical examples. Knowing reduction or curation distributions helps archaeologists to model and better understand assemblage formation and to interpret the size and composition of archaeological assemblages. It bears upon interpretations of the number of scrapers found in assemblages, their functional interpretation and even how their abundance, distribution and context of occurrence may register status differences within society (Hayden, 1993). Reduction is good to know for many reasons.

4. Applying reduction analysis

In North America, bifaces understandably attract the attention of archaeologists more than do other tool classes. Bifaces are abundant and highly variable in form in ways that implicate time, cultural affinity, transmission and activity. Elsewhere, various kinds of flake tools are more common and therefore more commonly studied by archaeologists. Whether or not associated with bifaces and retouched flakes, around the world unifacial sidescrapers and endscrapers that possess edges beveled by retouch are common. These may have several functions, but most are scraping or planing tools. Although sidescrapers and endscrapers may have differed in function and manner of use, morphological sidescrapers could be hafted and used as endscrapers (e.g., Nissen and Dittemore, 1974). Our subject is hidescrapers produced and used today among the Gamo of Ethiopia (Weedman, 2000, 2002a,b,c, 2005) (Fig. 3). Many are endscrapers, retouched on a bit that lies at the distal end of the flake blank. Some specimens have bits along lateral or proximal edges. Accordingly, we call these tools “hidescrapers” generically. Hidescrapers of broadly similar technology and use are documented elsewhere in the ethnographic record (e.g., Mason, 1891; Murdoch, 1892, pp. 294–298; Nelson, 1899, pp. 112–117). But scrapers also are abundant in prehistoric North American assemblages, particularly of Paleoeinidian age (e.g., Grimes and Grimes, 1985; Rule and Evans, 1985; Seeman et al., 1994; Wilmsen, 1968) and are common in other places and times (e.g., Ahler, 1975; Blades, 2003; Holdaway and Stern, 2004, pp. 227–236; Wheat, 1974). Although the technology, form, dimensions and patterns of use of prehistoric endscrapers probably were more diverse than ethnographic ones, the similarity in form and function makes ethnographic data at least broadly comparable to archaeological data. Accordingly, we study patterns of reduction in Gamo hidescrapers from Ethiopia as a general analogy to prehistoric endscrapers.

The Gamo are an agrarian peoples, who live in southwestern Ethiopia 350 km south of Addis Ababa to the west of the Rift Valley lakes of Abaya and Chamo. For 18 months between 1996 and 1998, Weedman lived among and studied Gamo hideworking practices. In particular she focused on 30 male hideworkers living in four villages: Mogesa, Patala, Eeyahoo, and Amure. The Gamo make their scrapers from cherts that erode down to the edges of river beds during the rainy season and more rarely out of obsidian which they collect off archaeological sites which now are agricultural fields. The scrapers are shaped and resharpened using an iron billet (Weedman, 2000, fig. 4-3). The Gamo use two different haft types, zucano and tutuma. The tutuma handle is a tubular-shaped piece of wood split open at one end to accommodate a single scraper, which is secured in place with twine into the open-socket (Fig. 4a). In contrast, the zucano handle accommodates one scraper on either side of the handle; tree resin holds the scraper in the closed socket (Fig. 4b).

The raw materials for tutuma scrapers are carried as small nodules to hideworkers’ households. In their gardens and near their scraping frames, hideworkers use an iron billet to reduce the nodules into several cores from which they produce flakes. Two to three flakes are selected from a core for hafting and use. The resulting tutuma scrapers are rarely shaped on the laterals or proximal, and thus often resemble modified flakes or informal tools in their unused form (Fig. 5a). Zucano scraper blanks are knapped using an iron billet at the quarry, then brought to the household. Next to the household hearth, the hideworker modifies the blank’s edges to fit in the haft, while the haft is resting near the fire to make the mastic malleable for inserting the scraper. Zucano scrapers are shaped on the distal, proximal, and one or more lateral edges; they resemble what archaeologists consider formal tools (Fig. 5b). Zucano and tutuma scrapers differ significantly in width, length, and thickness in their unused and discarded forms (Weedman, 2002a,b). While zucano scrapers are discarded once the working edge is exhausted, tutuma scrapers may be rotated so that a lateral or proximal edge is used as a secondary or tertiary scraping edge.

Gamo hideworkers use scrapers to remove the inner layer of fat from cattle hides to produce bedding. To process a single hide requires approximately 4 h to 3 min (cf. Weedman, 2002a, p. 735) where a slightly longer figure mistakenly was reported), during which time the hideworker uses approximately 4.5 scrapers. The tools are resharpened after a mean of 281 scrapes or 473 chops (Weedman, 2000, 2002a). Among all scrapers collected from the four villages, the unused (n = 811) and used-up/ discarded (n = 868) scraper morphologies are significantly different in maximum length, distal thickness, breadth/length ratio, thickness/length ratio, and edge angle. The Gamo learn how to produce their stone tools from their fathers and, since postmarital residence patterns are virilocal, a discrete village/lineage based scraper style is discernable and statistically viable (Weedman, 2000, 2002c). The increased presence of spurs (previously thought to have a secondary function) and increased breakage rates of Gamo stone scrapers were found to be associated with individuals who were either just learning how to produce tools or elderly hideworkers who were losing their strength (Weedman, 2002a). Gamo hideworkers produce unique scraper forms that differ from those in neighboring ethnic groups (Brandt and Weedman, 1997; Brandt et al., 1996).
5. Analytical approach

Earlier studies described the modern hideworking industries of Ethiopia (Clark and Kurashina, 1981; Gallagher, 1977; Haaland, 1987). These studies are invaluable but, consistent with their pioneering status, largely descriptive in character. Besides their intrinsic value, they inspired Weedman’s research. Her Gamo data are more thorough and systematic and they improve upon earlier studies in three important respects. First, Weedman observed and measured the amount of work conducted with hidescrapers. Second, she recorded the number of resharpening episodes that each hidescraper underwent. Third, Weedman measured length, width and thickness of scrapers before first use and at depletion, and measured length after each resharpening. Fig. 5 shows tutuma and zucano scraper blades at the point of depletion and discard.

In combination, data allow us to determine how tool allometry and perhaps geometry change during use and reduction. If original size of scraper blades can be inferred from geometric or allometric relationships between their dimensions, then amount of reduction can be estimated. Data also allow us to compare amount of work performed with amount of reduction in Gamo data, to determine if the two quantities are correlated. As a final possibility that we do not explore here, variation in amount of reduction among sets of hidescraper blades yields reduction or curation distributions that themselves can be analyzed, as above, for what they reveal about causes, patterns and rates of discard.

5.1. Zucano and tutuma scraper blades

Most archaeologists probably would recognize specimens mounted in zucano hafts as hidescraper blades. However, blades mounted in tutuma hafts resemble retouched flakes, or perhaps tula scraper blades (e.g., Tindale, 1965), more than formal tools like hidescrapers (Weedman, 2000, pp. 173–174). Considering the difference between them in flake technology, form, manner of hafting, and contexts of use...

Fig. 3. Location of Gamo Area, Southern Ethiopia.
and original (if not current) use (Weedman, 2000, p. 128), zucano and tutuma scraper blades merit separate analytical treatment.

Most scraper blades were hafted and used along one edge only. Three tutuma blades that were rehafted after first use and ultimately used and retouched on two or more edges were omitted from analysis. Although Weedman collected over 2000 tools, she directly observed the production and use of 65 zucano and 62 tutuma scraper blades. Weedman traveled to Gamo quarries and homesteads, where she observed both production and use. As above, hideworkers use several handle and scrapers during the processing of a single hide. Weedman color-coded each handle and handle side when necessary. She then used a tally counter to count the number of scrapes, chops, and resharpening blows for each scraper. When possible, she also measured the length of the scraper protruding from the haft after each resharpening episode. Each hideworking event was also videotaped as a cross-check of field data. Still, many specimens lacked some data needed in analysis, which considerably reduced the number studied here. Only 18 zucano and 33 tutuma scraper blades could be included in reduction analysis, depending upon the variables analyzed. All zucano specimens were composed of chert. Among tutuma blades, 28 were of chert and five of obsidian. Obsidian and chert scraper blades analyzed here did not differ significantly in dimensions (although they did in Weedman’s (2000, pp. 144–145) larger data set), so all were combined for analysis.

5.2. Methods and variables

Our measures of size, both before first use (original) and after last use (final), are orthogonal blade length, width, and thickness (Fig. 6). Some scraper blades were measured before hafting but some were not. For the latter, the length of blade exposed outside the haft was measured at first use and after each resharpening stage. Original length of these scraper blades was found first by determining haft length from the difference between length at discard once the blade was removed from the haft and exposed length after the last resharpening. Then haft length was added to exposed length at first use.

We calculated the difference between original and final dimensions (lendiff, widdiff, thkdiff) as absolute reduction measures, and the ratio of original to final dimensions (lentio, witratio, thkratio) as relative measures. Finally, we also...
computed direct absolute and relative (lendiff and lenratio) reduction measures for length at each resharpening stage from first use to fifth resharpening. Only three zucano scraper blades were resharpened six or more times, so we considered the behavior of reduction measures only for resharpening steps one through five. Only one tutuma scraper blade was resharpened more than twice, so analysis there is confined to the first two resharpenings.

Most scraper blades were measured only after they had been hafted, so could not be weighed. Most flake-blank platforms were removed from blades, especially zucano ones, before first use (Weedman, 2000, p. 124). Therefore, allometric measures based on relationships between platform dimensions and flake size (e.g., Davis and Shea, 1998; Dibble, 1997; Pelcin, 1997; Shott et al., 1999) could not be used. We do not consider technological attributes like plan form, cortex cover and dorsal faceting, because previous analysis showed little variation in these variables as a function of reduction (Weedman, 2000, p. 140).

6. Reduction in zucano scraper blades

Table 1 shows original and final values for zucano measures. Before considering zucano data in their own right, we briefly compare them to experimental and other ethnographic sources on hiddescraper use and reduction (see also Weedman, 2000, pp. 156—161). Overall form and technology of zucano scraper blades resembles other Ethiopian (Clark and Kurashina, 1981, fig. 21.3; Gallagher, 1977, fig. 2) and more distant (Murdoch, 1892, fig. 297) sources, although zucano blades may be less extensively faceted on their exterior surfaces. Original length of zucano blades (4.04 cm, n = 18) is less than the range of approximately 5—7 cm reported in most other Ethiopian source (Clark and Kurashina, 1981, tables 21.1, 25, 410, pp. 31, 67), although Giglioli (1889, pp. 213—214) described four specimens whose original length ranged from about 3.2 to 5.3 cm. Elsewhere, Murdoch (1892, p. 298) described a “newly made” Eskimo scraper blade that measured about 12.5 cm. Original width and thickness also are less than the range of 4—5 and 2—2.6 cm reported elsewhere (Clark and Kurashina, 1981, tables 21.1, 25, p. 410), although Haaland (1987, p. 67) reported only a minimum width of 2.0 cm that the Gamo value exceeds. Mean width of Eskimo scrapers is 3.9 cm (Nissen and Dittenmore, 1974, fig. 16), and those specimens were extensively resharpened. Mean thickness of the same specimens slightly exceeds the Gamo mean distal thickness. On balance, zucano scraper blades are somewhat smaller in general than other Ethiopian and ethnographic specimens.

Gallagher (1977, p. 411) reported about 100 scrapes between resharpenings; Clark and Kurashina (1981, table 21.1)

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and Haaland (1987, p. 69) reported even fewer. All such figures are much below the Zucano mean number of scrapes, let alone the combined mean for scrapes and chops. Broadbent and Knutsson’s (1975, p. 125) experimental hidescrapers were used for between 150–900 scrapes between resharpenings. Total Gamo scrapes and chops combined are very near the mean number of scrapes between resharpenings in Bronstein’s (1977, table 49) woodworking, not hideworking, experiments. Zucano mean and total scrapes are nearer to experimental than other Ethiopian values, although Broadbent and Knutsson’s experiments involved quartz and Bronstein’s chert was applied to presumably harder materials.

Number of resharpening episodes is not reported in other Ethiopian sources, although it is clear that at least several typically occurred. Elsewhere, Gould et al. (1971, p. 152) reported as many as 20 resharpenings of Australian flake tools (the Zucano maximum is eight). Giner and Sacchi (1994, table 1) reported one to four, and Bronstein (1977, table 49) an average of 4.3. Frison (1968, p. 152) inferred about five resharpenings for sidescrapers. Zucano figures seem typical of the limited available data.

Differences between average original and final length are about 2.5 to 3.5 cm by Gallagher’s (1977, fig. 13) and Clark and Kurashina’s (1981, table 21.1) accounts, and about 1.5 to 2.5 cm by Haaland’s (1987, pp. 67, 116). Even the lower figures reported elsewhere considerably exceed the Zucano mean for lendiff. As Weedman (2000, tables 4–10) noted before, Zucano scraper blades are not reduced the same absolute amount as other Ethiopian specimens. However, extrapolating from average original and final lengths as reported by Clark and Kurashina, Gallagher, and Haaland, the ratio of final to original length (i.e., lenratio) in those sources is about 0.5 to 0.65; the Zucano mean lenratio for relative reduction is not much higher than that range. Zucano blades are reduced a lesser absolute amount but nearly the same relative amount as other Ethiopian specimens. Gamo tools, mostly of chert, are smaller than most other Ethiopian cases perhaps because chert occurs in smaller nodules than does obsidian.

6.1. Results by resharpening episode

First we consider the changes wrought in scraper blades during the process of use and reduction by plotting dimensions by resharpening episode. The lower end of each episode’s range of length reduction of course is constrained at 0, but the upper ends of ranges generally decline as resharpening proceeds. Therefore, amount of length reduction decreases both in central tendency and range after the first resharpening episode; later episodes are more similar to one another. Resharpening episodes are not identical in their effects, the first reducing blades by about 0.4 cm, later ones by about 0.20-.25 cm.

6.2. Overall results

Length declines with use and width changes little. Distal thickness increases slightly with use as hidescrapers were reduced from their thinner distal to thicker proximal ends, although there is no difference in original and final median distal thickness (Fig. 7a, b). Lenfinal plus lendiff equals 4.041 cm, trivially different from average original length of 4.042. Average final distal thickness plus average thkdiff equals 0.653, very near average original distal thickness of 0.667. Lendiff is positive, thkdiff negative, while widdiff is near 0; length reduction is greater than thickness increase (Fig. 7c). As the ratio of final to original length, lenratio must be 1 or less. Final thickness exceeds original thickness, so thkratio is greater than 1. Original and final widths differ little, so widratio is near 1 (Fig. 7d).

6.2.1. PCA analysis

Principal-components analysis (PCA) is a data-reduction method that ordinarily would have little value in identifying dimensions of variation in only three original variables because those dimensions largely reside in the variables themselves. In this case, however, it reveals differences in proportions between original and final dimensions and suggests the factors that produced them. PCA of original values for length, width and thickness yields a single component whose eigenvalue exceeds 1, the conventional threshold for significance, but also a second component whose eigenvalue is 0.83 (Table 2). Combined, the two components account for about 79% of original variance. All dimensions load positively and highly on PC1, a general size component. PC2 is a shape component that emphasizes breadth and thickness.

PCA of final dimensions yields two significant components. Combined, they account for about 74% of variance. Length and thickness load highly on PC1, but length positively while thickness loads negatively; width has a low positive loading. Accordingly, PC1 can be interpreted as a reduction component that emphasizes the change in size and proportion that hide-scraper blades experience with use. All dimensions load positively on PC2, but only width highly so, and negatively; it is a simple narrow width component. Comparing the two results, PC1 is a simple size dimension in unreduced specimens, but a reduction dimension in depleted ones.

6.2.2. Reduction and work

Work measures include total number of scrapes and total number of chops. No hideworking is accomplished by blade resharpening, but we also treat number of resharpenings as a measure of work because resharpening increases with amount of work. Number of scrapes and number of resharpenings are not correlated, but other pairs of work measures are. Among other things, this result justifies treatment of resharpenings as a work measure, since it correlates with number of chops ($r = 0.74, p < 0.01$).

Among pairs of work and reduction measures, only number of resharpenings correlates with the length-reduction measures lendiff and lenratio (with lendiff, $r = 0.52, p = 0.07$; with lenratio, $r = -0.59, p = 0.03$). (Low numbers may counsel use of nonparametric Spearman’s $r_s$ but in almost all cases $r$ and $r_s$ yielded similar values and attained significance. We report
a only when it differs from r.). Not surprisingly, with more re-
sharpenings lendiff increases and lenratio declines (Fig. 8a, b).

6.2.3. Indirect reduction measures

As above, reduction can be measured directly as the differ-
ence between original and final length (lendiff) and as the ratio
of final to original length (lenratio). They are direct because
Weedman measured them in the field; they are not inferred af-
after the fact. But lendiff and lenratio are not known in archae-
ological cases, because no one was there to measure tools at
first use and afterward. Archaeologists must devise indirect
reduction measures from dimensions or properties of tools as
recovered. As direct measures, lendiff and lenratio can be
used to determine the validity of indirect measures.

6.2.4. Geometric measures

Kuhn (1990) estimated reduction as the ratio of t, thickness
on the retouched edge which varies in use, to T, maximum
thickness that tends not to vary in use. Its Australian advocates
call this ratio the “Kuhn Index” or the “Geometric Index of
Unifacial Reduction” (GIUR) (e.g., Clarkson and Lamb,
2005; Hiscock and Attenbrow, 2005; Hiscock and Clarkson,
2005). As above, for ease of reference we call it t/T. This
index’s value increases with reduction of unifaces that have
triangular sections, subject to assumptions noted above.

Proximal thickness was measured only once in zucano
scraper blades, and presumably did not change during use.
Distal thickness was measured only before and after, not dur-
ing, use, so its variation cannot be analyzed as was variation in
length. We approximate T as proximal thickness and t as distal
thickness. Before use, mean t/T = 0.53. After last use, mean
T/t = 0.68. This direction of change is consistent with other
studies, but the range is much narrower. In theory t/T ranges
from 0 to 1 and in controlled experiments it varied between
about 0.1 and 0.9 (Hiscock and Clarkson, 2005). In archaeo-
logical retouched flakes from Australia, t/T ranged from 0.12
to 1.00 (Hiscock and Attenbrow, 2005, table 62). Its much
higher minimum value here probably owes to some combina-
tion of flat triangular longitudinal sections and retouching of
the used edge before first use. The latter in particular would
truncate the lower end of t/T’s range because t at first use al-
ready is a relatively high value.

---

Table 2

<table>
<thead>
<tr>
<th>Principal component</th>
<th>Eigenvalue</th>
<th>% variance</th>
<th>Length</th>
<th>Width</th>
<th>Thickness</th>
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</table>

Fig. 7. Dimensions of zucano blades. (a) Original; (b) final; (c) absolute reduction; (d) relative reduction.
Gamo *zucano* scraper blades are hafted normal to their longitudinal axes and are used and retouched on distal or proximal edges. Morphologically, many are endscrapers, not the sidescrapers or retouched flakes for which \( t/T \) ordinarily is calculated. Yet *zucano* blades apparently have shallow triangular sections, so \( t/T \) increases with use and reduction. Because distal thickness, our nearest equivalent to \( t \), was not measured at each resharpening episode, we cannot plot \( t/T \)’s behavior across episodes, but there is no reason to doubt that it rises steadily if only narrowly considering the restricted range of final values. Whatever the case, its range is constrained in Gamo compared to Australian data. The index \( t/T \) deserves further evaluation in the study of endscraper, not just sidescraper and retouched flake, reduction. Compared to reduction measures discussed below, however, its limited variation in Gamo data justifies no further consideration.

6.2.5. Allometric measures

Lacking suitable geometric measures, allometric ones must be devised. As above, they might be ratios of changing dimensions to essentially unchanging ones. In the Gamo case, only length, width and thickness were measured during use, so they are the only candidates for allometric analysis. Length and proximal thickness are virtual constants in use; length declines and distal thickness rises during use. Length declines more than distal thickness rises, so we emphasize it.

Blades (2003, p. 147) treated thickness as a “rough estimate” of original flake area (product of length and width) but, following Dibble (1995, pp. 326–327), also proposed the ratio of surface area to maximum thickness as a “precise measure of overall mass removal” (Blades, 2003, p. 146). For Folsom bifaces, Buchanan (2006, p. 190) estimated “overall point size” as a function of area. Holdaway and Stern (2004, p. 174) suggested a ratio similar to Dibble’s, of length to thickness. Patten (2005, in press) expressed flake volume as a function of thickness. Jefferies (1990, p. 8) used ratios of blade length to bit width and of blade length to total length to measure degree of reduction in Middle Archaic biface scrapers.

We follow such allometric logic, and consider the relationship between flake thickness and size, as measured by area or volume. Accordingly, among possible ratios calculated from length, width and thickness, we use the ratio of the product of length and width (itself an estimate of surface area) to proximal thickness, as follows:

\[
\left( \frac{\text{length}}{\text{width}} \right) / \text{proximal thickness}
\]

We call this measure “area/thickness ratio” or “A/T.”

A/T has at once the virtue and vice of considering all three major linear dimensions of scraper blades. Length, width and thickness are easily measured and often are reported for hidescrapers, so the ratio can be calculated in many cases. It also takes into account simultaneous variation in all three dimensions. If length, width, and thickness pattern differently among assemblages, then A/T values will faithfully reflect that variation. Before first use, flake area takes its highest value. With use and resharpening, length declines as width changes little, so flake area declines. Proximal thickness, however, does not decline with use. Therefore, A/T decreases as reduction progresses. It is an inverse reduction measure because its value declines with amount of reduction. Accordingly, A/T should vary inversely with measures of work (number of scrapes, chops, and resharpenings) and with the absolute reduction measure lendiff. It should vary positively with the relative reduction measure lenratio.

Table 3 and Fig. 9 report lenratio and A/T at each resharpening stage. For lenratio, there is a steady if slightly uneven decline in central tendency but also, until the last one, a slight increase in range or dispersion at each stage. For A/T, there is an uncertain and uneven decline in central tendency by stage, with a slight reversal in median between resharpenings 2 and 3.
A/T also shows a near-steady decline in range or dispersion by stage. As expected, therefore, direct and indirect measures both decline with resharpening but not identically. From resharpening 1 to 3, lenratio and A/T are significantly correlated (at first resharpening, $r = 0.67, p = 0.01$; at second resharpening, $r = 0.73, p = 0.01$; at third resharpening, $r = 0.61, p = 0.06$); small numbers preclude analysis for subsequent stages. On balance, direct and indirect reduction measures pattern closely but not identically.

A/T correlates significantly with lendiff ($r = -0.58$, $p = 0.01$) and lenratio ($r = 0.58$, $p = 0.01$) (Fig. 10a, b), in the directions expected. The absolute reduction measure lendiff is estimated by linear regression as:

$$\text{lendiff} = 2.04 - 0.13(A/T)$$

where figures in parentheses are standard errors of regression. The relative reduction measure lenratio is estimated as:

$$\text{lenratio} = 0.50 + 0.31(A/T)$$

There is sufficient dispersion of cases to qualify regression estimates for individual scraper blades, but a robust statistical relationship exists between variables.

Note the correlation coefficients reported above. A/T and lenratio correlate more highly in stages 1–3 than they do overall. As use continues and reduction progresses, apparently the variables’ correlation weakens. The overall correlation is 0.58, so $r^2 = 0.34$; as measured by A/T, allometry accounts for about one-third of reduction variation in zucano scraper blades. A/T does measure degree of reduction. But other factors also are significant contributors, among them differences between

<table>
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<th>Stage</th>
<th>$n$</th>
<th>Lenratio Mean</th>
<th>Lenratio Median</th>
<th>A/T Mean</th>
<th>A/T Median</th>
<th>VR1 Mean</th>
<th>VR1 Median</th>
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<td>0.797</td>
<td>7.32</td>
<td>7.08</td>
<td>0.078</td>
<td>0.060</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>0.669</td>
<td>0.635</td>
<td>6.90</td>
<td>6.23</td>
<td>0.092</td>
<td>0.068</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>0.572</td>
<td>0.605</td>
<td>6.73</td>
<td>5.87</td>
<td>0.105</td>
<td>0.068</td>
</tr>
</tbody>
</table>

Fig. 9. Boxplots of reduction measures by resharpening episode: (a) lenratio; (b) A/T; (c) VR1.
blades in original size and technology, hafting, and between users in learning and age. Nine of the 15 hideworkers who used zucano blades and about half of the 12 tutuma hideworkers were still learning the craft or were elderly. Such men had higher rates of spurs on bits and of breakage, both of which are signs of skill that varies owing to learning or aging (Weedman, 2002a) that may cause variation independently of reduction.

6.2.6. Volumetric measure

Patten (2005, in press) suggested a second, volumetric, method to estimate original flake size and, by extension, reduction. In experimental flake blanks whose volume was measured directly as a control, Patten (in press) derived a volume estimate via the power function:

$$\text{Volume} = \frac{40.812}{C1} \times \left(\frac{\text{maximum thickness}}{C3} \right)^{2.42}$$

and found a close match between measured and estimated values. We call this estimate “VOL1.” A slightly different expression in Patten (2005, p. 165) yields nearly identical estimates. Patten also expressed flake volume as the arithmetic function:

$$\text{Volume} = (\text{length} \times \text{width} \times \text{thickness}) \times 0.256$$

We call this estimate “VOL2.” The two volumetric estimates scale very differently (in zucano specimens, VOL1 mean = 290.6, VOL2 mean = 6.8) but are highly correlated ($r = 0.90, p < 0.01$). The scale difference, particularly the high values for VOL1, does not concern us because we treat them as broad and robust, not precise, volume estimates. As Patten (in press) stressed, each industry or technology probably can be characterized by its own power function to express volume as a function of thickness, although functions may be similar. For instance, the multiplier 0.256 in VOL2 essentially divides by four the “box volume” (Patten, in press) found as the product of length, width and thickness. This quartering itself derives from the lenticular cross-section of the Folsom blanks with which Patten worked and thus approximates the fraction of the box volume that they comprise. Most Gamo zucano scraper blades probably have plano-convex cross-sections, most tutuma blades irregular ones. Rather than assume that all zucano cross-sections are similarly plano-convex or attempting to accommodate the variation in tutuma ones, we use Patten’s expression as presented.

If VOL2 estimates original flake volume, then flake volume at discard is estimated as:

$$\text{Final volume} = (\frac{\text{length at discard}}{C3} \times \frac{\text{width at discard}}{C3} \times \frac{\text{proximal thickness}}{C3}) \times 0.256$$

We call this quantity “FVOL.” Obviously, it can be estimated from archaeological specimens. The ratio of final to original volume is found as the ratio of FVOL to either original-volume estimate separately:

Volume ratio 1 = FVOL/VOL1

or

Volume ratio 2 = FVOL/VOL2

We call these ratios VR1 and VR2, respectively. VR1 is an indirect reduction measure that requires no ethnographic mediation because both of its volume estimates are taken from presumably constant maximum (here, proximal) thickness, which archaeologists can measure on discarded tools. Although the power-function VOL1 estimate of original volume and the arithmetic-function FVOL are scaled differently, both can be calculated from dimensions of archaeological specimens. Accordingly, we consider VR1 a second indirect archaeological reduction measure besides A/T. VR2 is a direct measure of reduction dependent upon ethnographic observation because original length, width and thickness must be known in order to estimate its denominator, VOL2. Although VR2 cannot be measured in archaeological specimens, we also examine it for its patterning with VR1.

VOL1 and VOL2 correlate with one another ($r = 0.64, p < 0.01$) and both also correlate with FVOL (for VOL1, $r = 0.76, p < 0.01$; for VOL2, $r = 0.78, p < 0.01$). VR1 declines from first to third resharpening episode (Table 3; Fig. 9c). Low numbers in remaining stages reverse the trend. Qualified by those low numbers, VR1 patterns ambiguously.
with reduction stage. Over the first three resharpenings, VR1 correlates significantly with A/T (at first resharpening, \( r = 0.92, p < 0.01 \); at second resharpening, \( r = 0.91, p < 0.01 \); at third resharpening, \( r = 0.85, p < 0.01 \) and at first two resharpenings it correlates weakly with lenratio \( (r = 0.49, p = 0.13) \); low numbers caution against analysis for later resharpenings. In discarded specimens, VR1 correlates poorly with direct reduction measures (with lendiff, \( r = -0.39, p = 0.09 \); with lenratio, \( r = 0.38, p = 0.10 \)) but very strongly with the other indirect archaeological reduction measure A/T \( (r = 0.89, p < 0.01) \) (Fig. 11).

6.2.7. Work measures and indirect reduction measures

Neither A/T nor VR1 correlate well with direct measures of work, although they pattern inversely as expected (e.g., as A/T declines, reduction and, by extension, work performed, increase). A/T correlates weakly with number of chops \( (r_s = -0.49, p = 0.08) \). Like A/T, VR1 patterns weakly with work measures, although again results approach significance with number of chops \( (r = -0.42, p = 0.08) \).

6.2.8. Other possible reduction measures using dimensions

Besides geometric and allometric measures, a simple measure like overall length itself should be considered. Simple it may be but, unfortunately, length is not a valid general measure of reduction because different lithic industries, traditions and hafting modes produce hiderscrapers that had very different starting values for length (e.g., Blades, 2003). For instance, Gamo zucano and tutuma scraper blades themselves differ in length at first use \( (t = 2.42, df = 46.8, p = 0.02) \), so could not be compared directly by length alone.

A/T and VR1 are valid indirect reduction measures calculated from the constantly varying product of length and width and constant proximal thickness. But width itself is practically constant in Gamo zucano scraper blades, so perhaps the even simpler ratios of length to width and length to thickness are equally valid reduction measures. Length:width and A/T correlate significantly only when a low outlier on the former is removed \( (r = 0.65, p < 0.01) \). Even without outlier removal, VR1 correlates similarly with length:width \( (r = 0.60, p = 0.01) \). Length:width also correlates with the direct reduction measures lendiff \( (r = -0.61, p = 0.02) \) and lenratio \( (r = 0.67, p = 0.01) \). Its correlation with the two direct reduction measures is slightly higher than with indirect measures. Zucano blades often have parallel margins (Fig. 5b). Hiderscraper blades with converging margins would not necessarily maintain near-constant width during use, so this ratio would not be a valid reduction measure for them. Length:thickness correlates with A/T \( (r = 0.85, p < 0.01) \) and VR1 \( (r = 0.87, p < 0.01) \). It also correlates with direct reduction measures lendiff \( (r = -0.53, p = 0.03) \) and lenratio \( (r = 0.54, p = 0.02) \) but slightly less well than does A/T. Length:thickness and, qualified by outlier removal and its assumption about outline form, length:width seem nearly as useful indirect reduction measures as A/T. Nevertheless, A/T correlates slightly better with direct reduction measures.

6.3. Summary

Length declines, distal thickness rises, and width changes little during use and resharpening. Overall, length reduction in zucano scraper blades from first use to depletion is little more than 1 cm from an original length of about 4 cm. Even though our sample is small, it is an accurate reflection of Weedman’s larger Gamo sample. There, length of unused zucano blades averaged 3.9 cm \( (n = 448) \), of discarded ones 2.83 cm \( (n = 489) \), also a difference of little more than 1 cm.

Although such modest reduction suggests low curation and somewhat casual use, “Gamo hide-workers do not discard scrapers before they are completely used-up” (Weedman, 2000, p. 139). With resharpening, not only do some dimensions change but tool proportions change as well. PCA of final dimensions parses variation into shape and reduced-size components because dimensions change in value and direction differently with use and resharpening. Varying dimensions means varying proportions, which implicates allometry.

Direct reduction measures can be estimated from the indirect measure A/T (less so from VR1), which archaeologists can calculate from dimensions of archaeological specimens. In this way, allometry permits archaeological inference from the observable (e.g., A/T) to the unobservable (specimen original size). Neither allometric measure is strongly correlated with direct work measures. Indirect measures are valid if imprecise estimates of reduction but not of work accomplished.

7. Reduction in tutuma scraper blades

Tutuma scraper blades are smaller generally but less homogeneous in technology and form than zucano ones. There are few detailed ethnographic accounts of the hafting and use of similar blades, so comparison of tutuma data to other sources is difficult. In some but not all respects, tutuma blades resemble Australian tulas (Holdaway and N. Stern, 2004, pp. 253–255; Tindale, 1965); a Tehuelche glass hiderscraper somewhat
resembles *tutumas* in size, form and hafting (Holmes, 1912, p. 141). Table 1 summarizes original and final dimensions of *tutuma* blades.

### 7.1. Results by resharpening step

As above, only 12 *tutuma* scraper blades were resharpened once, only six of them twice, and only one more than twice (it was resharpened nine times). Therefore, the behavior of direct reduction measures can be studied only in 12 blades for the first resharpening episode, and only six blades for the second one. *Tutuma* blades are only slightly reduced in the first resharpening (mean = 0.09 cm), more in the second (mean = 0.18 cm). Accordingly, lendiff doubles between first and second resharpening.

### 7.2. Overall results

Like *zucano* scraper blades, *tutuma* ones experienced some length reduction, virtually no width reduction, and thickness increase during use (Table 1; Fig. 12). The sum of lenfinal and lendiff is 3.732, trivially different from original length of 3.682. In this case, however, thickness increase was slight. Thkfinal minus thkdiff equals 0.644, trivially different from original thickness of 0.642. Overall, reduction in length exceeds change in other dimensions. Among direct relative measures of change, only lendiff is the mean and nearly the entire range less than 1. Widdiff values for width hover near 1, and thkdiff covers a wide range from less than 1 to over 2.

Among relative measures, only lenratio patterns consistently with resharpenings in the sense that all values are distributed in one direction (i.e., less than, not both less and greater than 1) and occupy a relatively narrow range. But its range is constrained by how lenratio is calculated.

#### 7.2.1. PCA analysis

Once again, principal-components analysis helps clarify the changes wrought by use and reduction (Table 4). Analysis of original values for length, width and thickness yields two components (PC2 has an eigenvalue slightly less than the conventional threshold value of 1) that account for about 85% of variance. PC1 is size generally; PC2 is a shape component that emphasizes width and thinness. Analysis of final values for the same variables yields two components that account for nearly 78% of variance. PC1 remains a size component, although it accounts for slightly less variance than does PC1 among original variables. PC2 again is a shape component (and again has an eigenvalue slightly below 1), now emphasizing narrowness and relative thickness. As with *zucano* scraper blades, PCA shows change in shape and proportions, not just size, with use and reduction. That is, it implicates allometry in the reduced size and altered shape of *tutuma* blades as a result of use and resharpening.

### 7.2.2. Reduction and work measures

All direct measures of work are highly correlated with one another. Most direct reduction measures are not, however, correlated with work measures. Only lendiff correlates weakly

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Fig. 12. Dimensions of *tutuma* blades. (a) Original; (b) final; (c) absolute reduction; (d) relative reduction.
with number of resharpenings \((r = -0.49, p = 0.11)\). Unfortunately, that correlation was forced by one outlier that underwent nine resharpenings. (Interestingly, this was the sole left-handed hideworker in Weedman’s study, a man well respected for the quality of his stone work, who knew how to extract the most from his tools.) Omitting it, the variables are not correlated. Similarly, most relative use measures do not correlate with work measures, only lenratio correlating weakly with number of resharpenings \((r = 0.49, p = 0.11)\). On balance, correlation between measures of work and use is poor.

7.2.3. Direct and indirect reduction measures

For zucano scraper blades, we took proximal thickness as the value of maximum thickness. Proximal thickness is known for very few tutuma blades, so cannot be used to calculate A/T. We use final distal thickness in its place because thickness generally (not always) increases with resharpening of tutuma scraper blade, so final thickness more closely approximates maximum thickness.

A/T declines from first to second resharpening (Fig. 13). At first resharpening, A/T and lenratio are weakly correlated \((r = 0.49, p = 0.13)\), which perhaps owes to low numbers and the relatively many among them with lenratio values of 1. The even lower numbers at second resharpening \((n = 5)\) preclude analysis. A/T correlates with thkdiff \((r = 0.37, p = 0.05)\) and with lenratio \((r = 0.34, p = 0.07)\). Thkdiff measures absolute reduction in distal thickness, which is not a common reduction measure. Despite somewhat weak results, we emphasize A/T’s correlation with lenratio. Fig. 14 plots lenratio as a function of A/T, regressing as follows:

\[
\text{lenratio} = 0.62 + 0.011(A/T) \\
(0.06) (0.006)
\]

qualified by the high slope coefficient relative to its value and the very low \(r^2\) of 0.14. A/T does pattern significantly with the direct relative reduction measure lenratio, although the predictive value of correlation is low. Like zucano scraper blades, tutuma ones preserve evidence in reduced form of their original size, but in this case it is more complicated by other factors.

As with A/T, we could not compute Patten’s volume measure using proximal thickness. Again, we used final distal thickness in its place. FVOL correlates with both VOL1 and VOL2 (for VOL1, \(r = 0.42, p = 0.02\); for VOL2, \(r = 0.59, p < 0.01\)), no surprise considering that original and final volume are calculated using some of the same dimensions and that, all else equal, we might expect longer original scraper blades to yield longer used and depleted ones. Indirect reduction estimates VR1 and VR2 correlate significantly with direct reduction measures, VR1 yielding higher coefficients but similar attained significance than VR2 with both lendiff and lenratio (with lendiff, \(r = -0.67, p < 0.01\); for lenratio, \(r = 0.66, p < 0.01\)) (Fig. 15).

As we noted in discussing zucano scraper blades, VR1 is a reduction estimate computed as a power function of maximum thickness alone, a dimension that presumably varies little with use and allometric change. This property makes it a suitable archaeological estimate of original size for use in estimating size reduction because it requires no mediation by ethnographic observation. Instead, maximum thickness can be measured directly on most archaeological specimens. VR1’s high correlation with both absolute and relative use measures suggests that length reduction can be estimated

### Table 4

Principal-components analysis of *tutuma* blades

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<thead>
<tr>
<th>Principal-component</th>
<th>Eigenvalue</th>
<th>% variance</th>
<th>Loadings</th>
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<td>-0.031</td>
</tr>
</tbody>
</table>

![Fig. 13. A/T before first and second resharpening.](image)

![Fig. 14. Lenratio against A/T.](image)
Comparing work measure.

episode in lute reduction, relative reduction is greater at each resharpening episode (especially the first) and overall. Like absolute more, and undergo greater absolute length reduction at each re-

Zucano scraper blades are longer at the outset, are resharpened less than length declines. But reduction does not scale similarly.

...types. In both, length declines substantially in use and reduc-
tutuma episodes are much higher for blades, however, this conclusion is qualified by the dispersion around Fig. 15’s regression line. The correlation is robust but somewhat imprecise for individual tools.

Because tutuma scraper blades are little modified and highly variable, we did not examine length:width or length:thickness ratios in tutuma data. Neither A/T nor VR1 correlate with any work measure.

8. Comparing zucano and tutuma scraper blades

Reduction patterns are somewhat similar between scraper types. In both, length declines substantially in use and reduction, width scarcely changes, and thickness increases, although less than length declines. But reduction does not scale similarly. Zucano scraper blades are longer at the outset, are resharpened more, and undergo greater absolute length reduction at each re-

The second resharpening, mean lenratio in zucano blades is 0.83 but 0.91 in tutuma ones. A/T values at the first two resharpening episodes are much higher for tutuma than zucano blades. Lenratio necessarily de-

Because some factors that determine degree of reduction. Consider an analogy to pencils. Their users reduce pencils to different degrees. They may do this as a matter of circumstance, discarding a pencil at completion of some episode of use such that amount of re-

...s, although Gamo hidescrapers documented elsewhere in Ethiopia. Scaper blade dimensions are changed differently in resharpening and reduction. Length declines, of course, because most Gamo tools are resharpened only on their distal edges. Proximal thickness probably remains unchanged, although this is impossible to confirm in our data. Distal thickness rises with reduction, considerably in zucano blades and slightly in tutuma ones. Width changes little in use.

Our results would be trivial if they amounted to no more than the conclusion that length declines as a result of resharpening. But scraper blade proportions change as overall size de-

Allometric variation is patterned such that absolute and relative amounts of reduction can be estimated in depleted specimens from A/T and VR1. Regression estimates of reduction are statistically robust but imprecise. But the two allometric measures also differ in results; A/T is a better estimator of ab-

...of one other type in the broader context of the many factors that determine degree of reduction. As above, we could consider them equally curated in the sense that most scraper blades of both types are used as much as they can be.

Among zucano scraper blades, A/T correlates somewhat better with direct reduction measures than does VR1. Among tutuma ones, VR1 correlates considerably better with reduction measures. The two indirect allometric reduction measures differ in their power to estimate reduction, depending upon blade type. A/T is computed from an area estimate, trivially, and thickness; VR1 is calculated from two volume estimates

(admittedly, themselves estimated from linear dimensions). Perhaps the greater modification of zucano blades before first use better standardizes them in size and form such that area is a more homogeneous size measure for them. Less modified tutuma blades may be better characterized by volume.

9. Analytical summary

Zucano scraper blades are larger and are resharpened more than tutuma ones. Neither type undergoes as much absolute re-

...manner of use, and how scraper blades articulate in use with worked material, zucano ones are better curated (sensu Shott, 1996) than are tutuma ones, although Gamo hideworkers apparently would consider them equally curated in the sense that most scraper blades of both types are used as much as they can be.

Among zucano scraper blades, A/T correlates somewhat better with direct reduction measures than does VR1. Among tutuma ones, VR1 correlates considerably better with reduction measures. The two indirect allometric reduction measures differ in their power to estimate reduction, depending upon blade type. A/T is computed from an area estimate, trivially, and thickness; VR1 is calculated from two volume estimates
length. All else equal, greater original variation and more dimensions of variation mean greater variation at discard. We should not expect allometric reduction measures to account for nearly all the variation that resides in discarded tools. In the Gamo case, they account for one-third or more of such variation ($r^2 = 0.34$ in A/T’s correlation with lenratio in *zucano* blades, and $r^2 = 0.44$ in VR1’s correlation with lenratio in *tutuma* ones). In view of complicating factors, these amounts are substantial for idiosyncratic manual crafts like stone tools.

The reduction thesis has far-reaching implications for classification and other kinds of lithic analysis. More reduction measures and the independent, perhaps experimental, validation of all reduction measures are urgent needs. A/T and VR1 can be added to the growing set of stone-tool reduction measures. Unfortunately, they perform differently depending upon tool type and they are not correlated with work measures. At least to judge from these results, reduction and work accomplished are different quantities. Amount of work performed using tools cannot be estimated from their allometric properties.

To continue the pencil analogy, length of reduced pencils is a good measure of amount or degree of reduction but not necessarily of use. Two people who begin to use identical pencils will not necessarily use them identically. One might sharpen her pencil as its tip dulled slightly, the other resharpen his only when the tip was blunted. Frequency of resharpening thereby complicates the relationship between work accomplished and reduction. Even if they resharpened the pencils the same number of times, one might reduce hers at each resharpening more than the other. Amount of resharpening similarly complicates the relationship. Even if they reduced their pencils to the very same final length, the users would not necessarily have used them in equal amounts, because one might press down on her pencil while writing more than did the other. As a result, the second user with the lighter hand would derive more use from his pencil than did the first user. Manner of use also complicates the relationship. One might use her pencil until it was a tiny stub, the other discard his when it is longer. Even differing personal notions of depletion complicate the relationship. Amount of work performed is one among several factors that collectively determine the amount of use and reduction that pencils receive. Pencils are reduced in use, and there are valid measures of their reduction. But those measures are not necessarily valid measures of their use. Even in highly standardized pencils, amount of use is difficult to infer from amount of reduction.

**10. Future directions in reduction analysis**

The nature of our data did not permit us to consider many reduction measures, and limited our treatment of many others. Only the allometric measures A/T and VR1 were analyzed in detail. Results are encouraging but they do not mean that only A/T and VR1 are valid reduction measures for Gamo and similar hiddescraper blades.

Today there are few prospective reduction measures validated in few cases. As research continues, however, more measures will be devised, tested and (hopefully) validated on more tool types and assemblages. Several measures are apt to correlate with one another, as do A/T and VR1 in this study and geometric measures in others depending upon tool types and other factors. In an experimental comparison, for instance, A/T was less effective than $t/T$ but more effective than other measures in explaining degree of reduction in retouched flakes (Hiscock and Clarkson, 2005, table 4). Eventually, we should know which measures are best for which types, and which ones are valid generally or only on particular types. It is difficult to imagine that any one reduction measure will be equally valid for all tool types in all contexts for all conceivable analytical purposes. But measures that are valid with many types will enable archaeologists to directly compare rates of reduction among those types.

At the same time we need more data, either ethnographic or experimental, on the relationship between amount of work accomplished, reduction, and reduction measures. Work accomplished might be measured in time, number of actions like strokes, scrapes, or firing of points, or amount of material worked (e.g., Broadbent and K. Knutsson, 1975; Bronstein, 1977; Kamminga, 1982; Shott, 2002). Both direct reduction measures and indirect geometric or allometric ones should be examined for their correlation with work measures. Until clear patterns emerge from such research, archaeologists can link indirect measures better to amount or degree of reduction than to work itself.

In degree and pattern, reduction is a fundamental property of many stone tools. It cannot be observed directly, but must be inferred. This quality may be one reason that some archaeologists are reluctant to consider, let alone measure, reduction. Age-at-death is a fundamental property of ancient people that must be inferred from their skeletal remains. This similar quality has not prevented paleodemographers from devising a range of age measures. Just because they cannot directly observe or record age does not discourage paleodemographers from inferring it.

In their ethnographic and experimental research, lithic analysts might emulate paleodemographers, who confront similar questions in estimating age-at-death in skeletal populations (Shott, 2005, p. 120). They use various morphological and histological measures that do not always yield identical values. In a controlled study, Meindl et al. (1983, pp. 75–76) calculated an average of several independent estimator’s values weighted by each one’s score on the first component of a principal-components analysis of all estimators. They argued that “the first component of a principal components analysis of the correlation matrix of the individual estimators of age is actual age” (Meindl et al., 1983, p. 76), and found that the several estimators varied in their intercorrelations and component loadings. All estimators were not equal.

Archaeologists might do the same in controlled experiments. One or several tools of one or several types can be fashioned, then dulled and resharpened several times. At each resharpening variables like dimensions, mass, and edge angles sufficient to calculate several reduction measures can be recorded. But other measures may be devised later. Because
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References


Andrefsky, W., 2006. Experimental and archaeological verification of an index of retouch for hafted bifaces, American Antiquity 71, in press.


