Journal of Archaeological Science 48 (2014) 129–138

Contents lists available at SciVerse ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Ground stone use-wear analysis: a review of terminology and experimental methods

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ARTICLE INFO

Article history:
Received 9 August 2012
Received in revised form
22 January 2013
Accepted 28 January 2013
Available online 7 March 2013

Keywords:
Ground stone
Use-wear
Tribology
Experiments
Wear mechanisms

ABSTRACT

Methods, terms, and experimental results are presented as standardized concepts for the analysis of ground stone tools. Recent experimental and microscopic research techniques applied to the study of ground stone tools have broadened the recognition of use-wear patterns. Building on the research of tribologists who study wear in order to prevent it, wear mechanisms have been identified that are distinctive to the relative nature of contact between two stone surfaces in addition to the nature of substances worked between contacting surfaces. Tribological wear mechanisms identifiable on stone surfaces include surface fatigue, adhesion, abrasion, and tribochemical interactions, each of which are continuously in play, so that what we see depends on when the wear process was interrupted. Other important factors influencing surface wear are the durability and texture of the rock type selected for tool use.

1. Introduction

The most basic research questions addressed by ground stone analyses are about the specific attributes that allow archaeologists to recognize tool manufacture, use, maintenance, and discard. Flaked lithic technologists began addressing these questions decades ago with use-wear research, evaluation of wear rates, and studies of kinetics (Amick and Mauldin, 1989; Bamforth, 2010; Carr and Bradbury, 2010; Hayden, 1979; Hayden and Kamminga, 1979; Keeley, 1980; Unger-Hamilton, 1984; Mathieu, 2002; Odell and Odell-Vereecken, 1980; Tringham et al., 1974; Vaughan, 1985), and they quickly realized the need for standardizing terms and analysis techniques (see for example, Hayden, 1979). Terms such as striations, abrasions, gouges, crushing, comet-shaped pits, micropolish, and edge rounding are now commonly used in flaked stone use-wear studies. Additionally, the relative usefulness of high power and low power magnification techniques, ethnographic analogy, and experimental replication have been evaluated by flaked lithic analysts.

Less attention has been paid to the standardization of terms and analysis techniques for stone tools used in percussion tasks, commonly referred to as hammerstones or pecking tools, as well as for tools used in or modified by grinding and crushing, commonly referred to as ground stone (but see Hayden, 1987:8–119; Semenov 1973; Woodbury, 1954). The pace, quantity, and quality of research on ground stone tools gained momentum during the 1990s and early 2000s with attempts to bring some level of standardization to the study of these tools (Adams, 1988, 1989, 2002; Mills, 1993; Wright, 1992, 1994; Wright, 1993). Now ground stone analysts world-wide have incorporated use-wear, experimental, and ethnographic concepts into their analysis techniques (Burton, 2007; Burton and Adams in press; Clemente et al., 2002; Dubreuil, 2001, 2004; Hamon, 2008; Procopiou et al., 2011; Vargiolu et al., 2007) with six researchers contributing to an international publication intent on standardizing techniques and terms for ground stone analysis (Adams et al., 2009).

The purpose of this paper is to make more accessible an analytical and terminological strategy for ground stone analysis that builds on the work of ground stone analysts with influence from tribologists who study wear for the express purpose of preventing it. Tribology, a sub discipline of engineering, is the science of interacting surfaces in relative motion specific to the study of friction, lubrication, and wear. Although the tribologists cited here have mainly worked with metal (Blau, 1989; Czichos, 1978; Dowson, 1979; Kato, 2002; Kragelsky et al., 1982; Quinn, 1971; Szeri, 1980), their classification of wear mechanisms is directly applicable to ground stone tools and their terms have meanings that warrant their adoption to facilitate communication about use-wear patterns on stone surfaces.

Tribologists define *wear* as the progressive loss of substance from the surface as a result of the relative motion between it and another contact surface (Czichos, 1978:98; Szeri, 1980:35; Teer and

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http://dx.doi.org/10.1016/j.jas.2013.01.030

Arnell, 1975:94). Such progressive loss is clearly discernible in the wearing of grinding and abrading tools. As used by archaeologists studying ground stone, use-wear analysis is the examination of an item for macroscopic and microscopic evidence that allows us to understand how it was altered, separating damage patterns caused by manufacturing techniques and post-depositional activities from those caused by use (Adams, 1988, 1989, 1993, 2002; Adams et al., 2009; Dubreuil, 2001, 2004; Dubreuil and Grosman, 2009; Hamon, 2008). Building on tribological definitions, four wear mechanisms are helpful in describing and understanding the formation of specific damage patterns on stone surfaces: *adhesive wear*, *abrasive wear*, *fatigue wear*, and *tribochemical wear*. These mechanisms are not mutually exclusive, nor independent in how they change surfaces. The four mechanisms interact, and one becomes dominant over the others depending on the characteristics of the contacting surfaces and the nature of any *intermediate substances* (Adams, 1988, 1989, 1993, 2002; Adams et al., 2009). These are important concepts for ground stone use-wear analysis because they provide a means for evaluating wear patterns without having to create an experimental example of every possible use situation.

a

b

Fig. 1. Macrotopography: (a) naturally rough and angular surface on a vesicular rock; (b) flat surface on a granular rock that is asperite enough to abrade a contact surface.

2. Surface analysis

The microscopic analysis of worn surfaces differs from that of flaked edges, mainly in depth and breadth of worn area, but also in the ability to place the larger tools under a microscope. Variations in ground-stone tool sizes require the use of microscopes with adjustable stands. Relatively low-power, binocular magnifications ranging from 20× to 100× have been most commonly used to scan for wear patterns across broad surfaces. The use of magnifications greater than 100× require the same due diligence by focusing on more than one tiny area to evaluate the extent of use and the differential interactions of wear mechanisms across the entire worn surface. Recent exploratory studies have evaluated casts of surfaces for use with Scanning Electron Microscopes or other systems that cannot accommodate large artifacts (Dubreuil, 2004:1617). Dubreuil comments that casts made of silicone provided the best results, but even these could not reach the deepest interstices of granular stone surfaces (Adams et al., 2009:54).

Surface analysis begins with an evaluation of *surface topography* (Adams, 2002:28–29; Adams et al., 2009). Topography can be described without magnification at a *macrotopographic* level and with magnification at a *microtopographic* level. The natural roughness, lamina, and angles in a stone surface are features of *macrotopography* (Fig. 1a). The surface of a stone with no macrotopographic relief appears flat (Fig. 1b), but this is not meant to imply that it is smooth. The surface of a tool made from granular rock might have no macrotopographic relief and still not be smooth because of the natural texture of the rock. In this sense the stone surface has *microtopography* that plays an important role in the formation of use-wear (Fig. 2). Surface topography at all levels is important when two surfaces come into contact. Between two hard or rigid contact surfaces only the higher elevations make initial contact, and this is where use-wear patterns first form. Softer contact surfaces engage the features of topographic relief in ways that are identifiable and classifiable as subsequently discussed.

How use-wear is recognized and described is influenced by the nature of the tool rock which must be understood before wear traces can be accurately distinguished. For example – is the natural granularity or texture of the stone rounded or angular? Are the grains cemented with a durable silica-based cement or a soft calcium carbonate? Are the vesicle margins sharp or rounded? Rock surfaces have natural topographic variability at both macroscopic and microscopic scales (Delgado-Raack et al., 2009). Use-wear on specific items should be evaluated against an area on the stone that is unused or broken so that the unmodified nature of the stone is known (Adams, 2002; Adams et al., 2009:45).

For analytical purposes, ground stone surfaces can be assessed in terms of durability and asperity (Adams, 2002:27–42; Adams et al., 2009). These concepts are relevant to the performance characteristics of rocks chosen for tools and to the alterations needed to make surfaces functional. Asperity is an important concept for understanding how use-wear patterns are created on ground stone surfaces (Adams, 1993, 2002:27–42). *An asperity* can be a single grain or a single projection from a surface, the spaces between asperities are *interstices*. *Asperity* is a combination of rock granularity and surface texture, and is influenced by rock durability. The surfaces of tools made from coarse-grain rock naturally have the potential to be more asperite than the surfaces of tools made from fine-grain rock (Fig. 3). The surface of a fine-grain rock or a water-worn cobble of any texture can be made more asperite by pecking it to sharpen the surface texture. If a smooth surface texture is desirable, a coarse-grain rock can be smoothed by leveling the grains. Thus, the term asperity is not necessarily related to the natural rock texture, but to the texture of the manufactured tool surface.

Through manufacture techniques or by use, the asperity of both fine-grain and coarse-grain rocks can be reduced to equally smooth surface textures. The asperite surface of a tool made from durable rock (some metamorphic and volcanic rocks) may not cause as

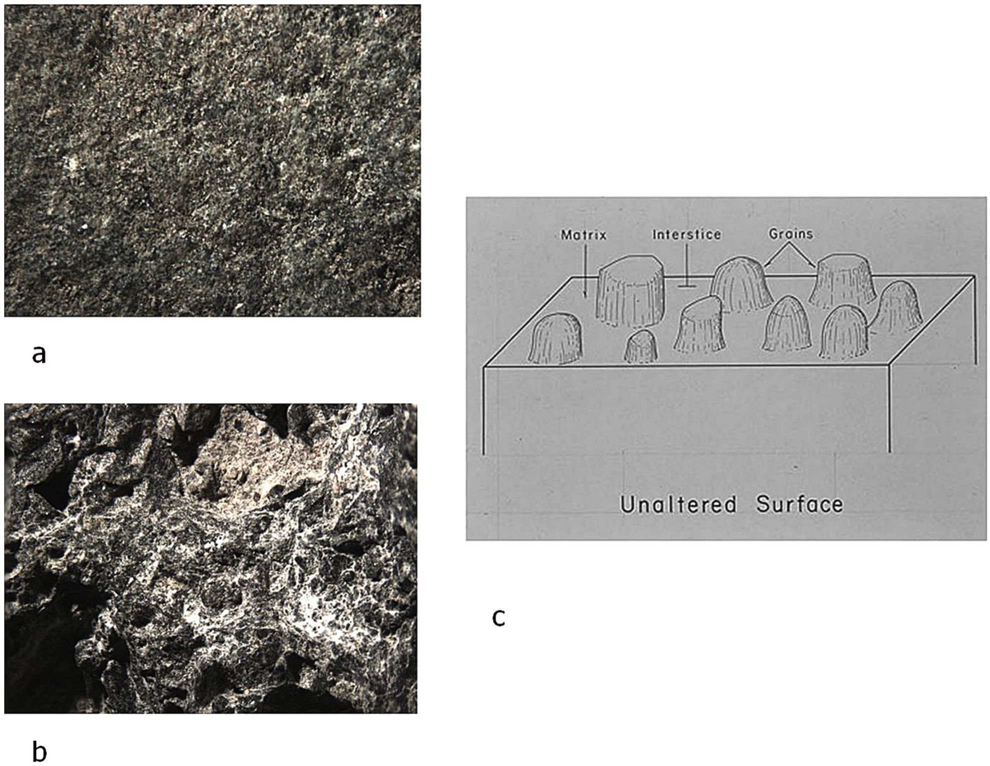

Fig. 2. Microtopography using an Olympus SZ1145 stereo microscope with a 3.2 Megapixel CMOS digital camera: (a) photomicrograph, 40×, of a fine-grain stone surface; (b) photomicrograph, 40×, of a vesicular stone surface; (c) line drawing of the microscopic features of an unaltered, granular stone surface. Line drawing by Ron Beckwith (Adams, 2002:Fig. 2.3).

much abrasive damage to a contact surface as an equally asperite surface of a tool made from weakly cemented rocks (some sedimentary rocks). Because the grains are easily dislodged from the weakly cemented rocks, the surface maintains its asperity longer but it also wears out faster than a tool of more durable rock. The surface of the durable rock wears smooth because no grains are dislodged. If abrasion is an important function of the tool then the smoothed surface must be resharpened.

Vesicular rocks vary in asperity depending on the closeness of their *vesicles* (the holes made by escaped gases during the formation of the rock) and the roughness of the *margins* (the edges between vesicles). Interstices and vesicles are important to evaluate

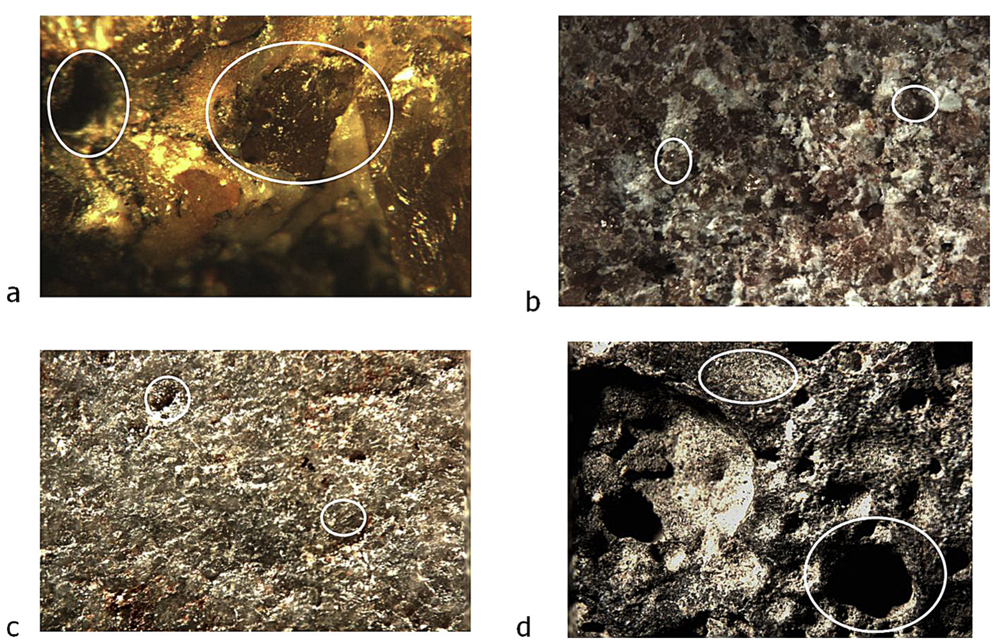

Fig. 3. Microtopographic features, 40×: (a) unused surface of a coarse-grain rock with an interstice in the left oval and an asperity in the right; (b) unused surface of a fine-grain rock with an asperity in the left oval and an interstice in the right; (c) used surface of a fine-grain rock with an interstice in the left oval and an asperity in the right; (d) lightly used surface of a vesicular basalt rock with a margin in the left oval and a vesicle in the right.

for evidence about the nature of the contacting surfaces. How far the wear extends into them is evidence of the relative rigidity of the opposite surface and the nature of any intermediate substance. These terms and concepts relating to surface topography provide a consistent, salient method for evaluating use-wear patterns.

Surface damage also happens after artifacts enter the archaeological record and can continue after they are extracted from the archaeological record. All stone tools emerge from their archaeological contexts covered in dirt and in certain environments covered with a layer of white calcium carbonate, commonly referred to as caliche. Individual bagging and labeling of artifacts protects them until they can be carefully cleaned according to the specifications of laboratories that run residue, pollen, or other special analyses, or until surface analysis is eminent. Gentle cleaning involves soaking the artifact in water and then loosening the dirt with a soft brush under running water. Caliche comes off with a dilute vinegar wash, or in the most stubborn cases, a 10-to-1 dilute solution of water to hydrochloric acid (used according to package instructions and protections), followed by a thorough rinse. A portion of the surface protected by the caliche can be left untouched for future analysis. Proper storage techniques protect the artifacts from rubbing against each other or from scraping against drawers and shelves. In most cases such post-use damage is identifiable as localized and intrusive into use-wear patterns.

3. Wear mechanisms

Tribologists have identified more wear mechanisms than those presented here, but this discussion includes those that are most obviously in operation on stone surfaces. As surfaces move against each other, the alternating stresses of movement, pressure, and impact instigate the mechanisms of adhesive wear, abrasive wear, and fatigue wear (Fig. 4). These mechanisms create surficial cracks on both contacting surfaces. Once a crack has formed, crack propagation results in the release of energy in the form of frictional heat (Czichos, 1978:105–112). The release of heat, through crack propagation and the breaking of molecular bonds, is only one of the factors important in the wearing of contacting surfaces. Other factors include any intermediate substances that are between the contacting surfaces. In the industrial world intermediate substances might be lubricants. In terms of traditional societies using ground stone tools, intermediate substances are grain, meat, clay or anything that is being processed between two stones (Adams, 2002:27–41). Properties of the contact surfaces themselves contribute to the wear process such as oils in hides or bone and the silica in vegetal remains. Additionally, environmental factors are important, including whether the surfaces are contacting in a wet or dry atmosphere, or in a clean or dirty context.

As a stone surface wears, the topography changes so that the most obvious damage visible is the result of the last wear mechanism in action when contact was interrupted. When two surfaces come into contact, even if there is no movement, they create molecular interactions. These interactions form bonds that are broken when one surface is moved against or away from the other surface (Czichos, 1978:119–123). This is *adhesive wear*. In the early stages of wear the damage may not be visible except at very high power magnification. However, as wear progresses the damage increases and interacts with the other mechanisms. Adhesive wear on ground stone surfaces is probably best seen where they are repeatedly handled, removing minute fragments of stone that adhere to fingers and hands and leaving behind hand oils that adhere to the stone. Such evidence is referred to as *prehensile wear* by other authors in this volume.

As pressure, impact, or the alternating stress of movement is applied to contacting surfaces, the highest elevations bear the weight and mass of the load. If the load is more than is bearable

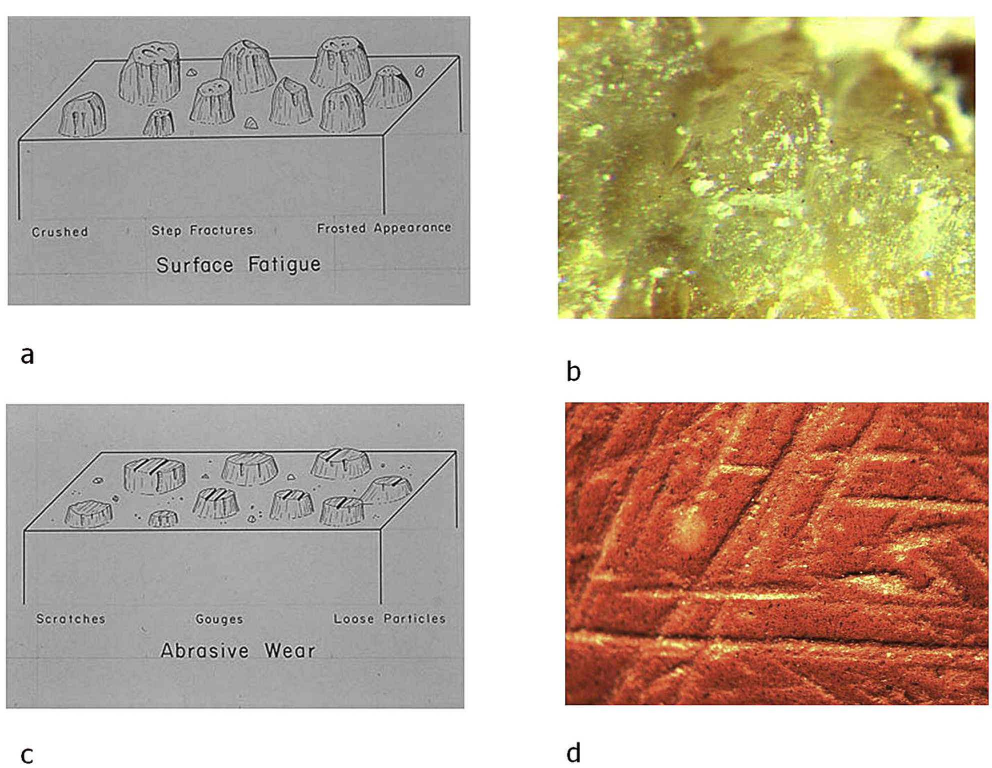

Fig. 4. Illustrations of surface fatigue and abrasive wear mechanisms: (a) line drawing of the damage patterns from surface fatigue on a granular rock surface; (b) photomicrograph, 40×, of the damage patterns from surface fatigue on a granular rock surface; (c) line drawing of the damage patterns from abrasive wear on a granular rock surface; (d) photomicrograph, 20x of the damage patterns from abrasive wear on a fine grain surface. Line drawing by Ron Beckwith (Adams, 2002:Figs. 2.4 and 2.5).

then there is collapse and crushing of the elevations (Czichos, 1978:105; Teer and Arnell, 1975:95). This crushing mechanism is *fatigue wear*. Damage is visible, both macroscopically and at low power magnification (less than 100 power), as cracks, step fractures, and pits. The effect is similar to that seen on frosted glass. Fatigue wear might destroy damage patterns created by adhesive wear, but also opens up fresh surface area upon which new adhesive bonds can be created. These areas of fatigue are impact fractures. Distinctive examples of impact fractures have been called pecking or peck marks and they are easily seen on pecking stones and hammerstones or the surfaces shaped by these tools.

Movement and the subsequent breaking of bonds release energy in the form of frictional heat and loosen rock grains and rock fragments from one or both surfaces. These loosened particles become *abrasive agents* in the wear process. Abrasive agents create scratches across the stone's surface and become involved in the abrasive wear process. *Abrasive wear* is also caused by the movement of a more durable, asperite surface across a softer, less asperite surface. The harder, rougher grains of the durable surface dig into the smoother, softer opposing surface and movement displaces the softer material, creating scratches in the direction of the movement (Czichos, 1978:126, Teer and Arnell, 1975:106). These scratches are descriptively referred to as *striations*, with deeper scratches sometimes called *gouges*; they are collectively referred to as *abrasion*.

Adhesive wear, abrasive wear, and fatigue wear create an environment for chemical interactions of the *tribochemical wear* mechanism (Fig. 5). These chemical interactions produce *reaction products* – the films and oxides that buildup on surfaces – that are referred to by tribologists as *sheen* (Czichos, 1978:123). Tribochemical interactions constantly occur on microscopic and macroscopic levels when two surfaces move against each other. These interactions are enhanced by frictional energy and mechanical activation. However, unless the reaction products are allowed to accumulate they are not readily visible. While the other three mechanisms constantly expose fresh surfaces upon which interactions can occur, they can concomitantly remove any buildup of reaction products. Reaction products continue to be removed until the higher elevations of the contacting surfaces are leveled to the point that fatigue wear is no longer a factor, and the asperities of the two surfaces are no longer gouging each other. *Leveled* surface topography and surface asperity allow the reaction products to buildup enough to be macroscopically visible as sheen. The continued development of sheen depends on the mineral composition and granularity of the rock, the nature of the contact surface and any intermediate substances, as well as the duration and intensity of use (Adams et al., 2009:50; Dubreuil, 2004; Procopiou et al., 2011).

The mechanisms of adhesive wear, abrasive wear, and fatigue wear are reductive processes as just described, each with distinctive damage patterns. Tribochemical wear, however, is cumulative, but only after the other wear mechanisms have leveled the surface enough to allow for the buildup of residues to become visible. Ultimately, use-wear patterns, including prehensile wear, on stone tools are combinations of mechanical and chemical interactions (Adams et al., 2009:54; Witthoft, 1967). Many of the wear mechanisms described above are recognized by flaked lithic analysts as evidenced by the papers included in this volume.

4. Experimental replication of wear on surfaces

The best way to recognize human processes in wear formation is through replication analysis, which provides the opportunity to record information about the unused surfaces, the interactions of intermediate substances, the nature of surface damage as wear progresses, the effects of motor habits on the formation of wear, and the nature of the contact surface. The success of this strategy is exemplified by various experiments that were implemented to

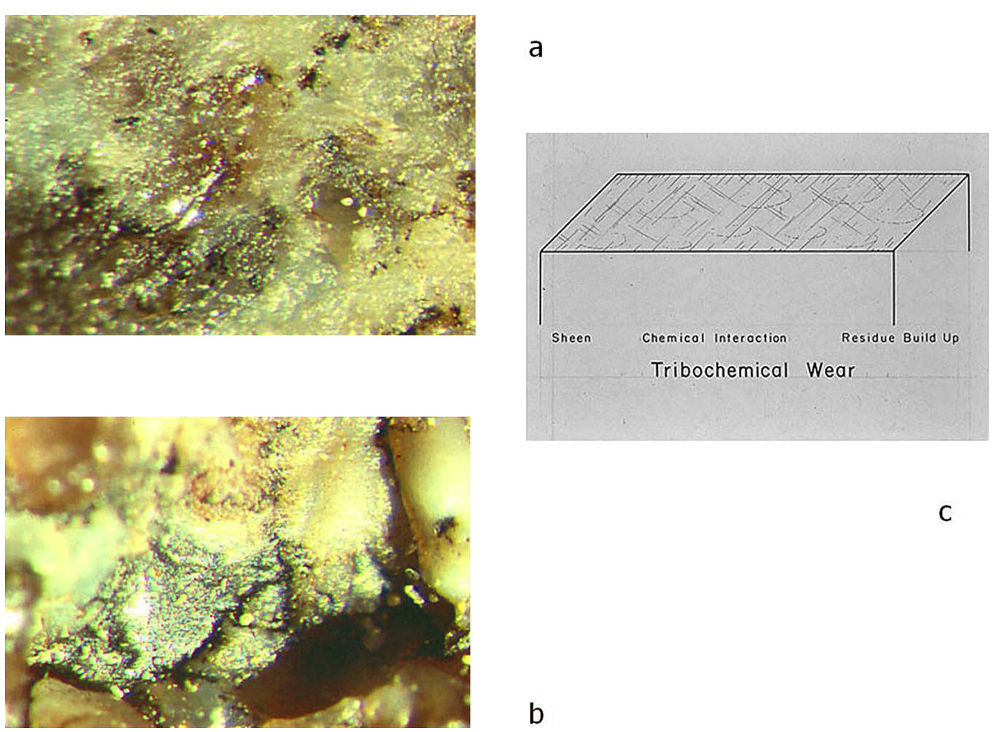

Fig. 5. Illustrations of tribochemical wear mechanisms: (a) photomicrograph, 40×, of tribochemical sheen on the surface of a fine-grain rock; (b) photomicrograph, 40×, of tribochemical sheen on a single grain in a coarse-grain rock; (c) line drawing of tribochemical wear on a well-worn surface. Line drawing by Ron Beckwith (Adams, 2002: Fig. 2.6).

create type collections of wear traces from grinding maize kernels, various small seeds from grasses, amaranth, chia, sunflower, clay, and temper; as well as from shaping and finishing objects made of clay, shell, wood, bone, and stone (Adams, 1988, 1989, 1993, 2002:33–41; Adams et al., 2009; Burton, 2007; Burton and Adams in press; Dubreuil, 2004; Dubreuil and Grosman, 2009; Hamon, 2008; Procopiou et al., 2011; Vargiolu et al., 2007). The experiments conducted so far have been exploratory, but in each task it has been possible to see damage patterns consistent with those identified by tribologists for the various wear mechanisms. The consequences of rock texture became obvious as did the utility of terms defined throughout this paper. The following discussion is based on experiments conducted by the author.

4.1. Experiment setup and results

The exploratory nature of the experiments was designed to evaluate which stone characteristics were important in the formation of wear on each tool and how long it took to see wear formation on each tool. The goal was to create a type collection of wear patterns on stone tool surfaces associated with specific contact situations, recognize kinetic patterns and morphological changes to tool shape during use, and evaluate the changes to the contact surfaces and any intermediate substances (Adams, 2002:27–41, 2010a). It became apparent almost immediately that use-wear forms rather rapidly on most contact surfaces, but the nature of the wear changes with continued use and reuse. Thus, like flaked stone analysts, ground stone analysts must address the issue of equifinality. While data were collected on how quickly tools were made, or substances were processed, at this exploratory stage of experimentation, efficiency rates should not be used to model the prehistoric past. Many more factors need to be controlled before the results can be used to evaluate tool efficiency (see Adams, 1999). The experiments referred to here were conducted strictly to explore the formation of use-wear and minimally, each experimental task accumulated 6 hours of wear. After use, the experimental grinding and processing tools were soaked in warm water with very dilute soap and the surfaces gently agitated in the water with fingers and a very soft, natural fiber brush. Polishers were lightly dry-brushed with a soft, natural fiber brush.

The framework for the experiments was derived from ethnographic accounts of specific activities such as food processing, and the working of hide, pottery, stone, wood, shell, and bone (Adams, 2002:27–41, 2010b). Food processing techniques are well known for Native American groups in the U.S. Southwest because not only were they documented by early ethnographers, but traditional food processing techniques remain in use today (Adams, 2010b; Bartlett, 1933; Hough, 1915; Underhill, 1939). Similarly, descriptions of traditional hide working techniques used by Hopi, Sioux, Blackfeet, Comanche and other tribes provide insight into how a rough stone was used during various stages of hide working (Adams, 1988; Belitz, 1979; Ewers, 1945; Kewanwytewa and Bartlett, 1946; Wallace and Hoebel, 1952). Pottery manufacturing techniques are also well described in the literature with rocks used in shaping and burnishing (Adams, 2010b; Shepard, 1956; Simpson, 1953; Spier, 1933). The use of stone to work other items is less often specified in the ethnographic literature so the experiments designed to work bone, wood, stone and shell are even more exploratory (Adams, 2010a). Most importantly, within the ethnographically derived model for each experiment, it was possible to recognize damage patterns on stone that were compatible with the descriptions of wear mechanisms defined by tribologists. These patterns are subsequently described in terms consistent with tribological principles that help standardize how ground stone analysts understand and describe use-wear.

4.2. Soft contact surfaces

Experiments with handstones and deer and elk hides highlighted the effects of wear mechanisms in action between an asperite stone surface and soft contact surfaces[1] (Adams, 1988, 2002:39–41) (Fig. 6). Wear mechanisms are activated by the soft, moist hide and the pressure of the abrading stokes of handstones made from granular and vesicular rocks. Fatigue wear is instigated with the first tool strokes and adhesive wear begins with contact against connective tissues and the hide. The interstices or vesicles in the stone surface become clogged with connective tissues and fat which reduces abrading efficiency. Efficiency can be restored with frequent submersion in water to cleanse the surface. The addition of water further lubricates the stone surface and disperses the heat generated by abrasion and crack propagation.

As the soft hide pushes into the depths of the interstices or vesicles, repeated strokes and downward pressure bring into play adhesive, abrasive, and tribological wear mechanisms. Because surface fatigue and abrasion are cushioned by the soft hide, leveling is minimal so that surface topography at both the macroscopic and microscopic level becomes distinctively smoothed but not leveled. Even though the hide is not inherently abrasive, microabrasion is caused by the movement of the softer hide against the surface microtopography. Grains dislodged from the stone or picked up in the working environment cause random, macroscopically obvious abrasions. The effects of chemical interactions are obvious by the sheen of reaction products built up on the smoothest areas of the asperities and interstices specifically, and generally across the entire stone surface. During later stages of hide processing, brains, colorants, or other products worked into the hide also become wear agents against the stone surface (Dubreuil and Grosman 2009).

The key performance characteristics of hide working stones, therefore, should be surfaces rough enough to abrade the fibrous connective tissues, soften the skin, or work substances into the skin. The appropriate surface texture can be an intrinsic attribute of a granular or vesicular rock texture, or the appropriate surface texture can be manufactured by grinding or percussion.

4.3. Hard contact surfaces

When two stone surfaces are worked against each other, the first points of contact are on the highest elevations of the surface. At the macroscopic level these are uneven bumps or ridges on the rock. At the microscopic level these are the tops of grains or high points in the margins of vesicles. The hard contacting surfaces do not push into topographic lows, interstices between the grains, or inside vesicles. If the load is unbearable, the higher elevations and the weaker grains are crushed or fractured as described by tribologists for surface fatigue. The warmth observable on a working stone surface during and immediately after use indicates the breaking of adhesive bonds and the generation of frictional heat during abrasive wear. If the movement of surfaces continues long enough to level the asperities, the buildup of tribochemical reaction products becomes visible as sheen.

The results are striking from exploratory experiments designed to discover the nature of wear patterns created by rubbing together pebbles of various textures.[1] If the topography of one surface is more asperite than the other, it abrades the smoother surface, leaving abrasions in the direction of movement. As the smoother surface moves, it levels the highest elevations of the rougher surface through surface fatigue and microabrasion. Continued use

[1] Documentation for unpublished experiments housed at Desert Archaeology, Inc., Tucson, Arizona.

a b

Fig. 6. Hide working experiments: (a) technician using a flaked tool to remove fibrous tissue for the hide; (b) technician using a handstone to remove fibrous tissue from the hide.

levels both surfaces until tribochemical sheen is visible on the smooth surface and the rougher surface is worn too smooth to abrade. Tribochemical sheen becomes visible on both surfaces when both surfaces are too smooth to abrade.

4.4. Resilient and pliable surfaces

Some contact surfaces are not as hard as stone or as soft as hide. Wood and bone surfaces, for example, range in nature from resilient to pliable depending on their freshness and exposure to weathering. Clearly, dried and green wood and bone surfaces have different resiliencies and interact differently with the asperities and interstices in stone surfaces. Resilient surfaces are not soft enough to reach into the bottoms of the interstices or vesicles of a stone surface like a soft hide does. Instead the edges of interstices and vesicles become rounded with more pliable contact surfaces engaging more of the asperity, interstice, or vesicle in the wear process than a resilient or hard contact surface. Green wood and bone also have resins or oils that add a chemical interaction to the wear process (Adams, 2002:37–39). Recent exploratory woodworking experiments demonstrated that tribochemical sheen builds quickly on stone surfaces used to work resilient surfaces.[1] Wood and bone surfaces worked with smooth stones become shiny and dense while the asperities of the stone tool surfaces become rounded with an evenly distributed sheen across the highest elevations and slightly into the interstices. Damage from abrasive and fatigue mechanisms is much less obvious both macroscopically and microscopically than on the surfaces of stones used to abrade stone surfaces.

4.5. Grinding

The function of *grinding* is to reduce intermediate substances to a product of appropriate texture by working them between two stones (Fig. 7). From the perspective of the U.S. Southwest, the term *grinding* is commonly used in connection with less formal, prehistoric processing techniques using two stones moved by human power, leaving the term *milling* for more mechanical techniques

a b

Fig. 7. Food processing experiments: (a) two metates made from different rock types used to grind popped maize kernels; (b) close up of fine-grained mano and metate.

that include compound tools with wooden handles, or that are moved by nonhuman power.

Whether they are food or nonfood products, intermediate substances can act as lubricants between the stones or become abrasive agents. Oily seeds lubricate contacting stone surfaces during grinding resulting in the formation of shiny reaction products whereas dried corn kernels, salt, and clays add abrasive agents between the contacting surfaces resulting in fatigue and abrasive wear (Adams, 2002:36–37, 1999:484–487). As grinding proceeds, intermediate substances fill the interstices or vesicles in the stone surface (see Fig. 7). This reduces the crushing effects of fatigue wear on the stone surface but also makes the surface less asperite, reducing the grinding efficiency of the stone. Once the surface is cleaned, roughness is restored, and the efficiency improves. Through time, stone grinding surfaces become leveled enough to lose efficiency and allow the residues to build enough to be seen as sheen – often called "corn gloss". Tool efficiency can be restored by the use of percussion techniques to resharpen the surface. No matter what is ground, the stones' surfaces all have at least a few striations and impact fractures from abrasive and fatigue wear mechanisms. The difference lies mainly in the more ubiquitous sheen that is created when oily substances are ground (Adams, 1993, 2002:36).

4.6. Wear as damage

Each experimental task consistently highlighted important wear factors such as friction-generated heat, removal of rock material from the working surface, grain rounding, grain leveling, the formation of sheen, and damage that impacted the surface topography at both a macroscopic and microscopic level. Measurements of damage on stone surfaces are difficult to quantify and standardize without specific equipment, and particularly when the original size of the tool is unknown. As an analytic construct, the amount of damage created through wear is classifiable using qualitative variables (Adams, 2002:25). For example, *light wear* leaves so little evidence that it can barely be seen with the unaided eye. *Moderate wear* is enough to leave obvious damage but not to alter the basic shape of the rock or tool. *Heavy wear* changes the natural or manufactured shape of the tool. Some tools have been used so much that they are difficult to hold for continued use, or the usable surface or edge is almost gone; these are *nearly worn out*. *Worn out* items are no longer usable in the activity for which they were designed. *Unused* items may have damage to their surfaces if, as part of the manufacture process, pecking or grinding was employed to create the surface, but there is no damage from use. If used consistently, these qualitative variables can be quantified in an assemblage for comparisons with other assemblages.

Wear management is a strategy of tool maintenance. A maintenance strategy for trough manos and metates is to widen the trough and replace worn manos with larger ones, thereby improving tool efficiency by enlarging the contact surface area. This wear-management strategy can be recognized by the presence of a ridge on the trough wall (Adams, 2002:Fig. 5.8). Various wear-management strategies also can be recognized for manos. One includes rotation so that the proximal edge, which receives the most pressure during use, becomes the distal edge. Such rotation alters the distribution of wear more evenly between front and back, thereby keeping the profile width uniform and the surface flat with a maximum area of contact between the mano and metate (Adams, 2002:112–114; Bartlett, 1933:15). Manos not maintained with such a strategy develop wedge-shaped profiles (Adams, 2002:Fig. 5.12). Another wear-management strategy is to create more than one usable surface on the mano. Two opposing surfaces allow the grinder to keep grinding until both surfaces become inefficiently smooth and require reroughening or replacement. Two adjacent surfaces allow the grinder to hold a thin mano so that her fingers are above the metate surface and out of harm's way. The mano shapes resulting from these wear maintenance strategies are not different mano types, just manos with different developments in their life history. The recognition of *wear management* and *tool maintenance* becomes important for distinguishing between the life history of the tool and the tool type. Eventually, any tool requiring a particular configuration or surface texture needs maintenance.

Additionally, the experiments have been useful for recognizing important *performance characteristics* that drive the selection of stones for specific tasks. For example, the performance characteristics that make a good polisher are size and texture. The surface must be smooth enough to create sheen on the contact surface and the size must be appropriate for the size and configuration of the contact surface. While the same size stone might be chosen for an abrader, the necessary performance characteristic is rough surface texture. The experiments have also been useful for understanding how the nature of the contact surface creates use-wear patterns on the polisher and the abrader. Not surprisingly, given the results from experiments conducted by flaked lithic analysts and the descriptions of wear mechanisms by tribologists, the surfaces of tools used in hide working, stone working, woodworking, and food grinding are each affected differently by the surfaces they contact and by intermediate substances.

The two most important facts to remember about wear patterns are: 1) because the formation of wear is an interactive process, visible use-wear is from the mechanism most recently in operation on the surface (Adams, 1988, 1989, 1993, 2002:32; Adams et al., 2009); and 2) the best way to evaluate use-wear is to compare it either to an unused area on the tool or to an unaltered piece of the same raw material. It is important to know what the unaltered rock looks like to distinguish natural processes from human processes. Experiments designed to asses post-depositional damage to surfaces caused by wind, water, freeze/thaw, and movement are particularly needed to help with this issue Further research into distinguishing wear patterns on ground stone surfaces would benefit from quantitative methods such as those developed for flaked lithic edges as discussed elsewhere in this special issue (Evans, Kimball et al., Macdonald, Stemp), but see also (Evans and Donahue, 2008; Stemp et al., 2009; Stemp and Stemp, 2001; Stevens et al., 2010).

5. Conclusion

Standardizing terms and methods for ground stone analysis is possible only if researchers communicate their research and analysis results in widely available media. By building on the work of tribologists, it has become possible to recognize use-wear patterns on ground stone tools that were created by specific wear mechanisms (Adams, 1988, 1989, 1993, 1999, 2002; Burton, 2007; Burton and Adams in press). We do not need to invent new jargon to discuss these mechanisms when evaluating stone surfaces for use-wear. Recent grinding and polishing experiments conducted by European researchers have described similar damage patterns on their experimental stone surfaces and had similar results to those reported here (Dubreuil, 2001, 2004; Dubreuil and Grosman, 2009; Hamon, 2008; Delgado-Raack and Risch, 2009), but experimentation anywhere with ground stone surfaces is still exploratory (Adams, 2010a). Experiments designed to test hypotheses or answer specific questions are rare (but see Mauldin, 1993; Mills, 1993; Wright, 1993). The next step in the scientific understanding of tool use requires hypothesis testing with confirmatory experiments (Adams, 2010b).

The appropriate hypothesis testing should include more controlled experiments using handstones made from various rock types to work hides and the surfaces of stone, wood, and bone objects. The exploratory experiments already conducted are useful for formulating hypotheses. For example, specific use-wear was identified on the quartzite and vesicular basalt handstones used to work hides. If the understanding of tribological mechanisms of wear on stone surfaces is accurate then the same mechanisms should be visible in operation of the surfaces of granitic and vesicular rhyolite handstones used to work hides. Similarly, other questions should be formulated that relate to the daily activities of processing and manufacturing. Is it possible to distinguish the sheen on bone polishers from that on wood polishers? Is there a difference in the sheen created by working a deer hide or a rabbit hide? How long does it take for wear to form on polishers used to burnish wood, stone, or bone surfaces? The answers to these and similar questions about tool use will provide much needed insight into the development of prehistoric technologies.

Acknowledgments

Many people have helped with the experiments over the years, but the most recent series were conducted with the help of Lauren Falvey, pictured in Figs. 6 and 7. I would also like to thank Jane Sliva and Stacy Ryan for their comments on earlier drafts of this paper and Jane in particular for toning my labored prose. Special thanks also to Harry Lerner for including me in the session, Standardization in Lithic Use-wear Analysis: How Do We Get There From Here?, at the 2011 meeting of the Society for American Archaeology in Sacramento and to George Odell who did not hesitate to include my ground stone research with articles about flaked lithic research.

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