Wear Traces and Projectile Impact: A Review of the Experimental and Archaeological Evidence

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Experimental and archaeological researchers have identified a variety of fracture or breakage types associated with stone implements used as projectile points. The mechanics of formation of the fracture types are similar regardless of mode of use: bow, atlatl, or thrusting. Even so, there continues to be some confusion and lack of standardization regarding terminology and the recognition of these fracture types. Identification of impact damage in lithic assemblages is facilitated by the isolation of both abrasive and fatigue wear and the adoption of standardized terminology. Impact-damaged artifacts can also provide relevant data pertaining to site function, patterns of weapons use and discard, and other aspects of subsistence behavior.

Introduction

The fracture patterns of chipped stone tools have been shown by both experimental and archaeological studies to be highly diagnostic indicators of various modes of tool manufacture and use (Ahler 1979, 1989, 1992; Boisvert 1980: 148–149; Callahan 1979; Dockall 1994; Dockall and Shafer 1993; Driskell 1986; Drollinger 1989; Hayden 1979; Johnson 1979, 1981a, 1981b; McAnany 1986, 1988; Odell 1977, 1979; Olausson 1983; Roper 1979; Semenov 1964; Shafer 1982: 31–33; Shea 1991; Torrence 1986; Young and Bonnicksen 1984). Such observations are useful in both technological and behavioral reconstructions of tool manufacture, use, and discard. Particular worked materials imprint diagnostic types of abrasive and fracture damage on the edges and tips of tools that can be used in the formulation of inferences regarding tool kinematics and task reconstruction.

Experimental researchers have identified a variety of fracture patterns that are diagnostic of tool manufacture. These patterns can be applied to lithic analysis in studies dealing with staging in manufacture and can indicate standardization in the reduction process. A series of distinct fracture types and patterns is also characteristic of chipped stone hunting implements. Fracture types characteristic of hunting with chipped stone projectile points have significance for such areas of research as the reconstruction of aspects of subsistence behaviors, associated patterns of weapons use and discard (Ahler 1971; Ahler and McMillan 1976; Driskell 1986), and hominid evolu-

tion (Anderson-Gerfaud 1990; Beyries 1988; Holdaway 1989; Shea 1991).

A detailed review of the archaeological and experimental literature dealing with the use of projectile points indicates that an array of different terms have been applied to discuss similar phenomena associated with impact damage. Archaeologists have produced a valuable body of data and interpretation regarding the formation of damage traces on projectile points but there has as yet been no synthesis of this information from both experimental and various archaeological contexts. The goals of this paper are threefold. First, it is necessary to review briefly the pertinent literature on the topic of projectile impact studies. Second, a synthesis of this data is crucial for isolating areas of common observation that are masked by the application of different terminologies. Third, areas of common observation are discussed in reference to a proposed standardized terminology for further research in projectile impact damage. The proposed terminology is not meant to supplant or replace the standard current terminology in use among archaeologists specializing in microwear or lithic technology (see Ho Ho Nomenclature Committee 1979). Rather, it is meant to serve as a frame of reference for recognition and interpretation of the several categories of impact damage. The categories discussed below are subject to a wide range of variation due to the many factors operating in concert during projectile impact. Variability of projectile point wear can be discussed within the context of this series of broad categories.

Mechanical engineering, materials sciences, and tribology have contributed a basic theoretical framework that is commonly applied in studies of friction and wear of materials. This theoretical framework includes the basic definitions and parameters of wear types, including abrasive, adhesive, corrosive, erosive, and fatigue (Buckley 1981; Czichos 1978; Moore 1975; Rigney 1981). The types of damage that accrue upon flaked stone artifacts employed as hafted tools are easily included within the limits of abrasive wear and fatigue wear.

Patterns of Impact Damage

Materials science terminology is adopted herein for the major groups of damage that occur on hafted projectile points: abrasive and fatigue wear. These wear traces are also diagnostic of the fracture mechanics of brittle solids subjected to both static and dynamic loadings (Cotterell and Kamminga 1987, 1990). Abrasive wear results in deformation in the form of polishes, dulling, and striation of the tool surface or edge but does not result in mechanical failure of the tool (Buckley 1981: 469–471). Fatigue wear results in the mechanical failure of the tool as the tensile strength of the raw material is exceeded by forces of impact (Buckley 1981: 500–505).

These wear types are not necessarily exclusive of one another, but are often observed in varying combinations dependent upon such variables as worked material, duration of tool use, and mode of use. Proposed terminology for abrasive wear types includes linear polishes, striations, surface- or edge-rounding, and dulling. Proposed fatigue wear terminology includes longitudinal macrofracture, lateral macrofracture, distal or transverse fracture, crushing or multiple step-fractures, and spin-off fractures. Discussion of similar observations from archaeological and experimental studies are summarized below in the context of the terminology proposed herein.

Abrasive Wear Types

LINEAR POLISHES

These features were defined by Fischer, Hansen, and Rasmussen (1984: 28) as linear “plastic” alterations of the tool surface that appear as “long, shining stripes.” Similar traces on Azilian points have been grouped with striations under the category of “microscopic, linear impact traces” by Moss (1983a: 152, 1983b: 95). Fischer, Hansen, and Rasmussen (1984) considered linear polishes to be a diagnostic trait of projectile points based upon both experimental and archaeological studies of Brommian points and transverse arrowheads represented in Late Glacial and Neolithic contexts in Denmark. These polishes are ori-

ented roughly parallel to the long axis of the point and can begin on an edge or occur on the surface (FIG. 1A, B).

Experimental data (Fischer, Hansen, and Rasmussen 1984) suggests that their formation is due to the detachment of small flakes or chips from the distal end of the point upon penetration and contact with resistant material such as bone. Moss (1983b: 95) suggested the same origin for similar bright, linear polishes on Azilian points. As the flakes are detached, they score or abrade the surface of the point, thus leaving a polished and scratched linear deformation (Fischer, Hansen, and Rasmussen 1984: 28–29). Some are also shown to initiate at the bottom of small fractures, where chips or flakes were detached from the distal end of the point.

Similar features have been described by glass and metal technology researchers as “sleeks” or “furrows” with the difference being that sleeks exhibit smooth and regular margins. Sleeks also result from the displacement of a hydrolized silica gel at the surface of the tool (Kamminga 1979: 148) while furrows are a result of the mechanical displacement of material. The term linear polishes is proposed in this review also because Kamminga (1979: 148) noted that most sleeks are not easily observed with reflected or incident light microscopy but are seen with scanning electron microscopy (SEM).

STRIATIONS

Striations, although not a common feature of impact fractures, have been noted in many instances, both experimental and archaeological (Ahler 1971: 86, 105; Ahler and McMillan 1976: 166–167; Fischer, Hansen, and Rasmussen 1984: 28; Moss 1983a, 1983b; Odell 1977: 250). Striations are formed by the removal of material from the tool surface in a linear pattern (Del Bene 1979: 169). Like the linear polishes described above, striations are largely confined to the surfaces of the projectile point. Most striations are understood to have developed under conditions of static loading (Del Bene 1979: 169). More relevant to impact damage are striations and scratches that are the probable result of microfracturing/crushing and deformation or the dislocation of tool fragments (Del Bene 1979: 169), which suggests that the striations are due to both fatigue wear and abrasive wear. The orientation of striations on projectile points with impact damage is also largely parallel to the long axis of the point (i.e., in the direction of impact).

Del Bene (1979: 169) points out that the morphology of a striation can usually be divided into two parts: the head and the tail. The visibility of striations and head/tail aspects will vary with the optical power of available microscopy. The head is characterized as an initially deep depres-

Figure 1. Illustrations and microwear photographs of impact damage types discussed in the text: A) linear polishes (LP) adjacent to distal termination of a longitudinal macrofracture; B) diffuse linear polishes (LP) below a transverse macrofracture; C) distal crushing and comminution (note series of hinge and step terminations) adjacent to a longitudinal macrofracture; D) longitudinal macrofracture with a bending initiation on opposing face of same projectile point as in 1C; E) lateral macrofracture with a bending initiation; F) basal lateral or longitudinal macrofracture with a bending initiation. This same specimen also exhibited an opposing snapped basal ear and distal crushing and comminution; G) spin-off fractures exhibiting cone (Hertzian) initiation and hinge terminations. Spin-off initiation was from a transverse snap fracture. The lateral barbs of this projectile point were also snapped. The outline drawings of projectile points for A, B, and G exhibit distal transverse snap fractures in addition to other mentioned types of impact damage.

sion at one end. The tail is a shallower depressed area at the opposite end of the striation. The head forms at initial contact with a resistant material fragment, while the tail forms as the "effective velocity" between the fragment and the surface increases or stresses decrease. Some striations may or may not have the head/tail morphology depending upon varying factors of formation. Striations, when they are present, often are distributed on the surface beneath the termination of larger transverse macrofractures that removed a portion or all of the point of the projectile (Fischer, Hansen, Rasmussen 1984: 28–31; Moss 1983a, 1983b).

Whereas the formation of linear polishes can be understood in terms of displacement or deformation of surface material, as with sleeks, striations can be likened to furrows (see Kamminga 1979: 148). The use of the term striation is proposed because it may not be possible in all instances for the use-wear analyst to distinguish between sleeks and furrows as defined by materials technology specialists. At this stage it is considered important for the analyst to recognize the differences even though a distinction may not be possible, especially if funding and equipment availability do not permit the application of high power microscopy, elaborate optics, or SEM capabilities.

SURFACE/EDGE-ROUNDING AND DULLING

Rounding and dulling of the surface or edge is a type of damage that is attritional in nature and can begin with dislocatory types of damage. Rounding and dulling are generally associated with more dominant types of wear, such as longitudinal and lateral macrofractures and can more aptly be considered as accessory wear types. Rounding and dulling often appear as microscopic smoothing of prominences and flake scar ridges along the edges and surfaces of a tool (FIG. 1A–C,E,F). Polish is generally imprinted over rounding and dulling, suggesting a continuum of formation in some instances. Dulling can be considered as isolated spots of smoothed microtopography of an edge or surface while rounding is a larger or more continuous area of microtopographic smoothing. Although this damage type has been recorded experimentally, it is not generally considered to be highly useful for identifying impact-damaged specimens (see Odell and Cowan 1986: 204) and should not be used in isolation of other indicators. Edge/surface-rounding and dulling were in almost every instance associated with projectiles that had been in contact with animal bone, but also, to a greater degree, soil and stones. Rounding and dulling along the edges of projectile points have also been cited as evidence that these implements served functions other than as projectile points, such as scraping and cutting tools. A classic example is Nance's (1971) interpretation of fine linear

striations and scratches along the lateral edges of obsidian Stockton points from central California.

Both Sheets (1973) and Keeley (1974) proposed that factors associated with either manufacture or use as projectile points probably produced the edge wear observed by Nance. Hester and Heizer (1973) also published a reply to Nance, in which a larger study sample was utilized (Nance's study consisted of 10 specimens while Hester and Heizer included 87 Stockton points, including two embedded in human bone). Based on their analysis, Hester and Heizer (1973: 220–221) were hesitant to consider the various abrasive damage types observed as evidence of cutting wear due to the absence of corresponding edge damage indicative of such tasks. Hester and Heizer (1973) also concluded that the presence of abrasive damage should not be used in isolation of other types of wear to identify the various functions of projectile points and other morphologically similar tools. Ahler and McMillan (1976: 167) applied an array of microwear criteria in assessing function of hafted bifaces. They noted that there was a high correlation of edge-rounding and smoothing associated with moderate to large transverse blade fractures indicative of a range of cutting and scraping activities at Rodgers Shelter, Missouri. This was supported by Ahler's earlier functional study of projectile points from this site (Ahler 1971). Ahler's interpretation of evidence of impact damage was limited to fracture types identified as either longitudinal or lateral macrofractures. Edge-rounding and other abrasive wear types were not specifically noted in association with these fracture types.

Surface- and edge-dulling, rounding, and/or smoothing can also be indicative of hafting or prehension traces that occurred during tool use. In some cases it may be possible to reconstruct aspects of tool hafting, how the tool was held in the hand, or whether it was wrapped in a protective covering during use. All of this information can be useful in reconstructing the exact nature of the use of projectile points as implements in extractive tasks such as hunting and butchering or processing of game. Haft wear can be a combination of unifacial feather-terminated microscars along the proximal end/basal area of a flake or biface and surficial smoothing and polish of flake scar ridges. This damage pattern is to be expected when the point has moved around in the haft during use and bindings and the shaft come in contact with the surface and edges of the tool (Keeley 1980, 1982; Odell 1981: 207; Shea 1991).

FATIGUE WEAR TYPES

There is a wider degree of variation and identified types of fatigue wear associated with impact damage of projectile points than abrasive wear types. Odell (1981: 206) noted

that it is difficult to describe any typical patterns of breakage of impact-damaged artifacts because these implements are subject to a wide array of "potential" angles of impact and fracture initiation. This is also due in part to variations in the overall surface topography of the projectile point and the pattern of flake scars and arrises.

Even though "typical" patterns cannot be reliably defined, there are certain aspects of fracture mechanics that can allow the analyst to eliminate other causes. Odell (1981: 206) has noted that forces upon impact are oriented longitudinally through the body of the point. Forces directed through the point usually result in Hertzian cone fracture initiations. Such initiations can favor one surface or a lateral edge producing easily recognized modes of impact damage.

As a point penetrates an object the lateral edges come into contact with the material. Contact between the target material and lateral edges produces forces identical to those associated with cutting. This lateral edge wear is characterized by cone- and bending-initiated fractures that propagate at an oblique angle to the edge axis (Odell 1981: 206; but also see Cotterell and Kamminga 1979, 1987; Ho Ho Nomenclature Committee 1979). Wear produced under these circumstances can resemble cutting wear and functional interpretations should be made cautiously.

In addition to cone initiation, other fractures can initiate that are not related to the cone variety (see Tsirk 1979: 85). Such fractures begin at a greater distance from the contact area and bending forces contribute to tensile stresses resulting in initiation (Tsirk 1979: 86).

LONGITUDINAL MACROFRACTURE

One of the most prevalent modes of impact fracture could be termed as the longitudinal macrofracture (FIG. 1D). The basic characteristics of this mode of damage include the failure of the distal region of the projectile through either cone- or bending-initiation with propagation along one surface. Ahler and others (Ahler 1971: 85–86; Ahler and McMillan 1976: 166) have documented "longitudinally oriented flake scars" as direct evidence of the use of points as projectiles. This is supported by both experimental and archaeological studies of the lithic assemblage. This fracture mode was an important macroscopic indicator of projectile point function during the analysis of the archaeological assemblage from Rodgers Shelter. Several specimens of Hell Gap points recovered from the Casper site also exhibited impact scars resembling fluting channels on one or both faces initiating from the tip (Frison 1974: 96–98). Both hinge and feather terminations were noted by Frison.

Odell and Cowan (1986: 204) have documented experi-

mentally the variation of this damage mode using both bifacial points and selected flakes. Variation was described using patterns of initiation and termination. Variation included step/hinge and snap-and-step fractures. Fischer, Hansen, Rasmussen (1984: 23) noted identical impact damage on experimental and archaeological arrowpoints. Terminology was also based on initiation and termination variation: "feather terminating bending fracture," "hinge terminating bending fracture," and "step terminating bending fracture." Cone initiations were included as one group regardless of termination type. Archaeological analyses have also documented this mode of fracture, applying various other descriptive terms. Bradley (1982: 197) termed a similar damage type observed on Agate Basin points as an "impact channel" or "impact flute." Bergman and Newcomer (1983: 241) described a "flute-like fracture" and a "bending fracture." Both are defined as having a fracture that travels down one surface of the point, with the "bending fracture" qualified as not having a cone initiation. Bergman and Newcomer (1983: figs. 1.1, 1.2, 2.1–2.3) illustrated several archaeological and experimental examples of Ksar Akil points from Lebanon. Tanged points from Tell Abu Hureyra, Syria, also exhibit similar fractures (Moss 1983b: 149, fig. 2, specimen AH127).

Longitudinal macrofractures have recently been identified on Levallois points from several Levantine Mousterian sites (Shea 1988, 1991). Shea (1988: 443) noted that the most common fracture mode associated with Levallois points and flakes greater than 5 cm in length is a "single, large step- or hinge-terminated fracture" that propagates from the tip across the ventral surface. One final observation concerning longitudinal macrofracture needs to be mentioned. This mode of fracture during impact need not be represented by a single large longitudinal flake scar; multiple small flake scars can also occur, depending upon several factors such as target material, rate of loading, tool material, angle of impact, contact area, surface topography of the point, and dominant forces during fracture initiation.

LATERAL MACROFRACTURE

Another easily recognized but often misinterpreted impact fracture is the lateral macrofracture (FIG. 1E). As the name implies, the mode of damage involves the removal of a macroscopic flake scar that propagates along one of the lateral edges of the point or flake. Misinterpretation occurs due to the difficulty of distinguishing it from a deliberate burin blow or *technique du coup du burin* (Tixier 1974: 9). Occasionally this fracture type can be found to have initiated from the basal edge and to have propagated a short distance up the lateral edge of the haft element (FIG. 1F).

Experimental use of Clovis points as thrusting spears produced basal lateral macrofractures and associated crushing of the ears of the point bases (Huckell 1982). Similar damage has been reported or illustrated from other Paleo-Indian sites as well indicating that this type of damage may be diagnostic of the use of lanceolate points as hunting implements (Bradley and Frison 1987: 202, figs. 6.1b, h; Bradley 1982: 196, fig. 3.9e; Haury 1953: fig. 6e, f, and h; McCary 1975).

It is probable that lateral macrofracture is largely the result of cone initiation from loading forces oriented through the body of the point (Odell 1981: 206). The term lateral macrofracture is proposed here as an alternate term to both distinguish it from a deliberate burin blow (see above) and to disassociate this mode of fracture from classic burin technology. Epstein (1963: 187–201) described a number of projectile points from archaeological assemblages in Texas identified as “burin-faceted.” Numerous other experimental and archaeological studies have documented this mode of fracture and have referred to it by a variety of terms, all reinforcing the use of burin terminology. This variety in terminology can cause confusion with projectile points that also exhibit deliberate burin spall removals (see Epstein 1963).

Bergman and Newcomer (1983: 241) have defined a “burin-like fracture” in which one or multiple “slivers” detach from the lateral edge resembling a deliberately manufactured burin. Odell and Cowan (1986: 204) identified a “burination” fracture again based on visual similarity with the burin spall removal surface. Moss (1983a, 1983b) groups lateral macrofracture damage under “impact fracture” (or IF) and does not discuss variation but does illustrate an archaeological example from Tell Abu Hureyra, Syria, with this type of fracture (Moss 1983a: 149, fig. 2, specimen AHP 139). In an analysis of refitted arrowpoints from Plains Village contexts, Ahler (1992: 45) noted that such a fracture can sometimes result in longitudinal splitting of the point, with the fracture face having ripple marks indicating the direction of fracture propagation. Identical features on Agate Basin points were termed “impact burin” by Bradley (1982: 197). Frison (1974: 96–98) illustrated this type of macrofracture observed on Hell Gap points but did not identify it with a specific term.

Lateral macrofractures have also been identified in Levantine Mousterian lithic assemblages, primarily associated with retouched and unmodified Levallois points. Shea (1988: 443–444) noted that if a larger impact fracture propagates obliquely, following a lateral tool edge, it will resemble the burin blow, but will lack characteristic crushing and edge damage. These fractures were identified on a Levallois point from Hayonim Cave.

DISTAL OR TRANSVERSE FRACTURE

Distal or transverse breakage is more difficult to assign strictly to projectile impact. Forces that result in a distal or transverse bending (or snap) fracture during impact can also occur during manufacture or use. In fact, in some instances, it can be difficult or impossible to isolate the cause of breakage. Distal fracture is characterized by complete removal of the distal portion of the point resulting from bending forces (FIG. 1G). The exact processes that result in transverse breakage can best be understood by considering the dynamics of stresses involved (Truncer 1990: 19). Transverse fractures generally result from stress forces that act against the blade faces from opposing directions and can be produced by a range of processes (see Truncer 1990). Ahler (1992: 44) described the transverse fracture as characterized by a “flat, untwisted, unlippled, and otherwise featureless fracture plane through the tool which is oriented roughly parallel to the longitudinal axis.”

In an experimental and archaeological study of Perkio-men point breakage patterns, Truncer (1990: 17) noted that transverse fractures without either step or hinge terminations on one face of the point could not be used to accurately identify impact damage. This study also demonstrated that transverse fracture can result from other processes such as plow damage, manufacture, use, and trampling. Specific distinctions were made among distal, mesial, and proximal transverse fractures.

Ahler (1971: 58, 79) stated that transverse fractures are indicative of the use of points for purposes other than as projectiles. Dart point experiments by Ahler demonstrated a high correlation of transverse fracture with abrasive damage such as edge-rounding and smoothing. This suite of features is interpreted as indicative of miscellaneous scraping and cutting tasks.

Experimental studies by Fischer, Hansen, and Rasmussen (1984: 23) also noted the “snap terminating bending fracture” as a pattern of macroscopic damage on their projectile points. Bergman and Newcomer (1983: 241–242) identified “bending fractures” on Ksar Akil points and noted the absence of a positive or negative bulb of percussion. Transverse fractures that are associated with Middle Paleolithic pointed tools in the Levant are not distinctly referable to use as projectile points because of equifinality with other causes of breakage—use, manufacture, and accident (Shea 1988). Experimental use of Levallois points as hafted cutting and scraping tools demonstrates that transverse fractures are associated with these tasks (Shea 1988: 443). These results indicate that transverse fractures should not be used in isolation as an indicator of use as projectile points.

CRUSHING, "COMMINUTION," OR MULTIPLE STEP-FRACTURES

There is little documentation of crushing, comminution, or multiple step-fractures on projectile points, which can be considered diagnostic of projectile impact as either longitudinal or lateral macrofracture. It can also be used in association with other damage signatures as evidence of projectile point use such as longitudinally oriented striations, tip and edge abrasion/polish, or "spin-off" fractures. This damage mode is often characterized by a series of step-terminated fractures clustered at the distal end of the point, often on one surface (FIG. 1C). In some instances these step fractures can cascade down one surface. The forces that result in this type of damage are directed deeply into the interior of the point and are dissipated before propagation could remove a single large flake (Odell and Cowan 1986: 204), causing the damage to remain isolated at the tip.

Such damage has been noted on both archaeological and experimental Levantine Mousterian hafted Levallois points, flakes, and blades (Shea 1988, 1991). Frison (1974: 96) also describes tip crushing for a number of Hell Gap points from the Casper site. Several variations of this type of impact damage were identified but all exhibited destruction of the tip with a small portion of the tip snapped off (Frison 1974: 96). The damage could form during such tasks as cutting or scraping, piercing tasks such as drilling, awling, or boring, or in association with butchery tasks. The majority of these tasks involve the application of dynamic or static loading to the distal area of the tool in use. The direction of loading is considered to be parallel to the point long axis.

SPIN-OFF FRACTURES

Experimental studies using replicated Brommian points (Fischer, Hansen, and Rasmussen 1984: 23) led to the identification of a small accessory fracture associated with transverse and longitudinal impact fractures. These accessory types were also identified on archaeological specimens of Brommian points (Fischer, Hansen, and Rasmussen 1984). Known as spin-off fractures, these small features are identified by a cone initiation from a bending fracture surface that removes portions of the surface of the projectile point (FIG. 1G). The size and location of spin-offs is correlated with the nature of the forces associated with the bending fracture from which they initiate. Bending fractures that result from forces that are perpendicular to the projectile point face and length of the point will initiate spin-offs only on one surface. If spin-offs are present on both surfaces of the bending fracture, it is possible that they are the result of torsion or movement of the projectile

or point fragments in the target. Experimental studies have also isolated a size range for spin-off fractures resulting from projectile impact (Fischer, Hansen, Rasmussen 1984: 24). For the largest Brommian points, spin-offs approaching 6 mm or more are considered diagnostic. Transverse arrowheads and other small points usually had spin-off fractures of about 1 mm in length.

Correlation of Archaeological and Experimental Studies

Table 1 provides a correlation of experimental and archaeological studies briefly mentioned in the text with the proposed terminology and the diagnostic utility of various types of observed impact damage. The bias of most researchers to base inferences of projectile impact upon macroscopic traces associated with fatigue wear is apparent in the number of studies that have not addressed microscopic forms of wear that may be diagnostic or associated with projectile impact. These studies also indicate that longitudinal macrofractures, lateral macrofractures, and distal crushing/comminution are diagnostic of the use of flaked stone artifacts as hafted projectile points. Spin-off fractures have been under-utilized as an additional line of evidence of projectile impact. Distal or transverse breakage is not a good indicator of use of artifacts as projectile points when used in isolation of other lines of evidence. Microscopic use-wear traces are also under-utilized and can greatly enhance interpretations of the functions of hafted stone tools that may have also served as projectile points. The majority of these studies (TABLE 1) briefly mention microscopic traces associated with macroscopic forms of damage but were not specific regarding their utility in diagnosing the function of projectile points.

Further experimental research and analysis of archaeological collections will be necessary before the full potential of microscopic wear analysis can be applied to an understanding of projectile point impact damage. The studies that have been conducted to date indicate that this area of research will be an important aspect of behavioral research associated with prehistoric lithic assemblages.

Summary

The damage associated with the use of various suitable flakes and pointed tools as projectile points can be divided into two broad categories based upon fracture mechanics and associated physical forces: abrasive and fatigue wear. Abrasive wear is further subdivided into both linear polishes and striations and surface/edge rounding and dulling. Fatigue wear can be subdivided into longitudinal macrofracture, lateral macrofracture, distal or transverse fracture, crushing/comminution or multiple step frac-

Table 1. Use-wear studies and the inferred utility of these traces as diagnostic of projectile impact. In some instances the inferred utility of these traces is based upon their identification in text description or photographs within the article. Otherwise, the wear type was considered as not discussed. 0 = Not discussed; 1 = Diagnostic; 2 = Equivocal; 3 = Non-diagnostic.

Source	Linear polish	Striae	Edge rounding	Longit. macro.	Lateral macro.	Distal break	Distal crushing	"Spin-offs"
Shea 1988	0	0	3	1	1	3	1	0
Anderson-Gerfaud 1990	0	0	0	0	0	0	0	0
Beyries 1988	0	0	0	0	0	0	0	0
Holdaway 1989	0	0	0	0	0	2	0	0
Shea 1991	0	0	3	1	1	3	1	0
Shea 1990	0	0	0	0	0	2	0	0
Bergman and Newcomer 1983	0	0	0	1	1	1	0	0
Moss 1983a	1	0	0	1	1	0	1	0
Patterson 1994	0	0	0	1	1	2	1	0
Fischer, Hansen, and Rasmussen 1984	1	1	0	1	0	0	0	1
Truncer 1990	0	0	0	1	1	3	0	0
Odell and Cowan 1986	0	0	0	1	1	2	2	0
Grieser 1977	0	0	2	1	1	2	0	0
Ahler 1992	0	0	0	1	1	2	1	0
Huckell 1982	0	0	0	0	0	1	0	0
Roemer 1989	0	2	2	1	1	2	0	0
Frison and Stanford 1982	0	0	0	1	1	2	1	0
Frison 1974	0	0	0	1	1	0	1	1
Odell 1977	1	1	1	1	1	0	1	0

tures, and spin-off fractures. Variation in fatigue wear is due to variation in contact material (hide, bone, soil, stones, wood, etc.), angle of contact (perpendicular, parallel, or oblique to long axis of point), and forces in operation during impact (conchoidal, bending, compressive). Based on the presence of edge-rounding and other abrasive wear types in association with impact damage, it is highly probable that this wear is not due to secondary use of the projectile as a cutting/butchering implement; rather it is probable that abrasive wear represents the accrual of edge damage over an extended period of projectile point use until failure on impact.

It is crucial to realize that all of these types of wear can be produced by impact against a variety of organic and inorganic materials or produced by other factors such as manufacture. The inference of hafted projectile points serving secondary purposes as hafted butchering and cutting tools needs to be explored further through a series of replicative and experimental studies. More attention also needs to be given to the processes that can and could produce edge wear on projectile points and other hafted bifacial implements in order to eliminate the possibility of equifinality in microwear development.

A brief summary of fracture and abrasive wear patterns associated with the use of pointed tools and flakes as

projectile points indicates that these patterns are diagnostic and to some extent exclusive to the use of projectile armatures, whether propelled by hand, spear thrower, or through the use of a bow. The recognition of these various damage patterns in a lithic assemblage can add significantly to the behavioral information that can be recovered. This behavioral information can then be incorporated into the reconstruction of subsistence strategies at archaeological sites which will broaden the understanding of site function and activities.

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