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STARTING FROM SCRATCH: THE HISTORY OF EDGE-WEAR RESEARCH FROM 1838 TO 1978

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AUTHOR'S NOTE

Since this review was completed (March 1979), the excellent and thought-provoking papers from the Lithic Use-Wear Conference at Simon Fraser University have been published (Hayden 1979). Because the papers are so comprehensive and often revolutionary, I have judged that including them here would have necessitated considerable revision. Therefore, I have decided to leave the history as it was as of 1979.

INTRODUCTION

The history of lithic edge-wear research[1] in the West will be traced through the major lines of development that have characterized it from its inception 140 years ago. Emphasis will be placed on the developments of the last decade, however, when the pace and complexity of research have increased markedly. Such a study must be selective in its themes, and emphasis will be placed upon the technical and methodological aspects of edge-wear research. Theoretical questions, such as the rationale for conducting edge-wear research (Odell 1975) and the place of edge-wear research in the larger archeological context, will not be discussed here. Although as broad a spectrum of the literature as possible has been included, language limitations have unfortunately prohibited the inclusion of research from Eastern Europe and Russia. The reader is referred to Levitt (1979) for a description of the considerable edge-wear research carried out in Russia.

Study of the literature dealing with edge-wear (Table 1) indicates several trends: increasing awareness of the multiple factors influencing edge-wear on an object; increasing control in experiments designed to investigate these factors; and increasing refinement of techniques for observing and recording edge-wear. This is especially evident in the study of cryptocrystalline materials.

Table 1:

YEAR	NAME	MECH. ACTION	TOOL MAT.	MAT. WKED.	MANF. SCARS	EDGE ANGLE	WORKING ANGLE	EDGE MORPH.	NATURE	POST EXC.	TIME	FORCE	INNOVATION
1884	Spurrell				•								
1892	Spurrell	•			•								
1897	Evans	•					•						
1914	Molr		•						•				Early experiments
	Quente	•	•	•									
	Warren								•			•	
1920	Vayson	•			•								
1922	Vayson	•		•									Ethnography & e-w
1930	Curwen	•	•	•									
1957	Nero	•	•	•	•		•					•	Load on tool
1962	Sonnenfeld	•	•	•			•				•		Rigorous exp.
1964	Semenov	•	•	•	•		•						Systematic exp & e-w
1965	Mauser			•		•	•						Modern analogies
1966	Keller	•	•	•		•					•		Systematic research
	Gramsch	•	•	•									
1968	Frison				•								Tool resharpening
	White	•	•	•		•	•	•			•		Ethnographic study
	Wilmsen					•							Edge angle
	MacDonald & Sanger		•		•								Photomicrography
	Crabtree & Davis	•	•	•	•								Holistic study
1970	Kantman	•	•								•	•	
1971	Ahler	•	•	•		•							Glossary of wear
	Nance	•	•			•							
	Gould, Koster, Sontz	•	•	•	•	•	•				•		Ethnog. & exp.
	Tringham			•			•						Photo before use
	Rosenfeld	•			•								
	Kantman			•	•	•					•	•	
	Lenoir	•					•						
	Gunn						•	•					Dynamic analysis
1973	Sheets		•		•								Replication & e-w
	Hester, Gilbow, Albee	•	•	•		•	•	•					
	Hayden & Kamminga	•	•	•		•	•						
1974	Keeley	•	•	•	•				•				Direct verification
	Tringham et al.	•	•	•	•	•	•	•	•	•	•	•	Thorough experiments
1975	Brose		•	•		•				•	•		Chemical analysis
	Ranere	•	•	•	•	•							Complete collection
	Broadbent & Knutsson	•	•	•		•	•				•		Edge stability
	Odell	•	•	•	•		•	•			•		Summary & rec.
1976	Pant	•	•	•	•	•							
	Stapert								•				Natural causes of e-w
	Briuer	•		•						•			Chemical analysis
	Knutsson	•	•	•								•	
	Price-Beggerly	•	•	•	•	•	•	•		•	•	•	
1977	Walker & Long	•		•			•	•				•	Material worked
	Keeley & Newcomer	•	•	•	•	•	•	•			•	•	Test of e-w analysis
	Schousboe		•			•				•			Methodical
1978	Odell	•	•	•	•			•			•		
	Seltzer		•			•		•					
	Brink	•	•	•	•	•	•				•	•	Influence of grit

Illustrating an increasing awareness of the factors which can cause edge-wear on lithic materials. An • indicates which variables were considered in experiments, or simply an explicit recognition by the author of their importance to edge-wear analysis.

APPROACHES TO THE STUDY OF EDGE WEAR

Ethnographic parallels

Macro-examination of the edges of stone tools, and common sense inferences about their use, began in the 1830's with Nilsson, who noted that "through carefully examining how tools were worn, one can often with certainty conclude how they were used (Nilsson 1838-43:49; my translation)." He made considerable use of ethnographic analogy to determine the probable uses of tools from the past. Evans (1897) also drew heavily on ethnology for theories of use; but unlike Nilsson, Evans failed to return to his archeological specimens to compare their worn edges with those from his ethnographic populations. Pfeiffer's 1912 monograph was mainly devoted to replicative experiments, although he also

[1] I will define lithic edge-wear research as the study of alteration on the edges of humanly-modified lithic materials. Microwear research is then the microscopic study of such alteration, and use-wear is alteration due to use. In this paper "edge-wear" will be understood to mean the study of lithic materials only.

studied gross use-wear and ethnographic examples of use, thus providing a surprisingly advanced study of both the technological as well as the functional aspects of edge-wear. Vayson (1922) was concerned that the indiscriminate use of ethnographic parallels, if not accompanied by examinations of edge-wear, could lead to faulty interpretations of use; i.e., identity of form need not mean identity of use (Vayson 1922:34). He illustrated his point by showing that, on the basis of similar wear traces, an "hache néolithique" and an Eskimo scraper were used in the same way (Vayson 1922:36).

Many years later, White provided the edge-wear analyst with a controlled study of factors that can lead to edge-wear. The results of his study of simple stone tool use among New Guineans were no doubt disconcerting to the still-fledgling "science" of edge-wear analysis, as he concluded that "not all types of use produced macroscopic traces of wear on all tools at all times (White 1968:514)." However, on the basis of macrowear, White concluded that it was possible to distinguish between the mechanical actions for which most tools were used (p. 515). White's report is notable as one of the first systematic presentations of testing edge-wear hypotheses against actual use by stone-tool using peoples.

Taking ethnographic reasoning one step further, Knutsson (1976) investigated ethnographic evidence concerning the morphology and use of Eskimo bone and iron scrapers. Using this information, he believed he discovered the pertinent factors to consider in designing experiments employing experimentally-made quartz scrapers. In turn, he compared wear on the latter with wear on scrapers from an Upper Paleolithic collection from northern Germany, inferring how and on what materials the archeological specimens were used. A similar method of employing ethnographic evidence is seen in Gould, Koster and Sontz (1971). Rather than being content to use similarities in edge-wear on ethnographic and archeological adzes to denote similarity of use, they employed ethnographic evidence to construct experiments for using replicas of the aboriginal tools. Thus they were able to note the distinctive wear which resulted on adze flakes from planing wood (p. 160). Taking their results a step further, they hypothesized from comparison of this wear with that found on Quina-type scrapers that the latter were also woodworking tools (p. 166). However, they caution that their experiments have shown only that woodworking *can* result in the particular wear pattern they observed, not that woodworking is the *only* action that can produce such wear. They have thus avoided a logical pitfall which many edge-wear analysts fall prey to.

Another "ethnographic" approach compares modern metal tools with morphologically similar stone tools. Both Mauser (1965) and Semenov (1964) state that they have used this approach.

Thus, a progression can be seen from the notion that similarity in form denotes similarity in use, to comparisons of the edge-wear on ethnographic and archeological artifacts, to employing ethnographic examples to design realistic experiments and applying the results of both experimental and ethnographic study to hypothesize the function of lithic artifacts. However, although ethnographic example was considered as a fruitful source for hypotheses about function, most contemporary edge-wear researchers have relied more heavily on experimentation.

Experimental replication and use

Even in the earliest functional studies controlled experimentation was advocated as a means of producing wear patterns comparable to those on archeological specimens in order to infer function. For example, Sehested, by means of experiments with different kinds of grinding and polishing, tried to duplicate striations he had noted on stone axes (Sehested 1884:4f). Spurrell's article of 1892 also represents a well-reasoned example of the use of experiment in edge-wear analysis. He describes experiments in which he tries to duplicate the polish he observed on early sickle blades by sawing bone, horn, ripe straw, wood, and vegetable matter with experimental blades. He found that only in cutting ripe straw could he produce the varnish-like polish he noted on his archeological blades (Spurrell 1892:58). Curwen's experiments of 40 years later (1930) are quite similar in design, with the addition of a notation of the length of time he used his experimental flakes. He also provides photographs of his results.

In the midst of the controversy over whether eoliths were natural or man-made (Johnson 1978:343f), two of the opponents, Moir and Warren, advocated using experiments to demonstrate the influence of natural causes in producing "edge-wear" on the stones. Warren was a strong advocate: "Experiment should hold a similar position in these problems to that which it holds in physics or in chemistry (Warren 1914:413)." Warren's experiments are a well-reasoned investigation into the manner in which natural forces could cause the striations of the kind observed on eoliths. Notable here is the fact that, although he felt he had demonstrated that such forces could have caused the striations, he refrained from claiming this as the only possible cause for them. Other authors (cf. above) were not as prudent. Moir's paper of the same year is also an experimental investigation into possible natural causes of striations and other wear on flint. His experiments are not as thorough as Warren's; but like Warren, he also includes photomicrographs to report his results (Moir 1914).

While this controversy was being discussed in England, Quente was quietly and methodically conducting experiments in hafting and using axes and celts in Germany. His report is an example of a thoughtful approach in which he combined edge-wear research and experiment in order to arrive at conclusions regarding the mechanical traces of hafting on archeological specimens. Quente began by examining archeological celts for use-wear through a magnifying glass; and this is one of the earliest uses of magnification. Experiments in plowing and hoeing and a comparison of resultant edge-wear with that on the archeological tools enabled him to state with some assurance the probable mode of use and material worked by many celts and axes (Quente 1914). Such an ongoing feedback process between experiment and edge-wear analysis is a profitable one, becoming increasingly popular as edge-wear research continued (e.g., Ranere 1975).

There was little activity in experimental edge-wear between Curwen's 1930 article and the publication of Semenov's monograph in 1957. Western archeologists were apparently unaware of Semenov's book until Neustupny's review of the Russian edition in 1961. Perhaps the first mention in English of the work was in Sonnenfeld's study of celts, published in 1962. Although Sonnenfeld apologizes that his work was done before he knew of Semenov's and is less systematic, his analysis is notable for its rigorous experimental design and for the excellence of the photomicrographs. Through edge-wear analysis and experiment Sonnenfeld tried to "determine if there was a relationship between form and function which could yield to form a determining role as a criterion of function (1962:56)." He systematically investigated the influence of hafting, lithic types, soil type, angle of use, and the length of time the celts were used, thus producing one of the first studies which combined controlled experiment with conscientious reporting of resultant edge-wear. Sonnenfeld advocates systematic analysis to demonstrate how wear patterns develop through use, since, once the purpose of a tool is known, it should be possible to gauge its efficiency through experiments (p. 63).

An early example of the conscientious application of Semenov's techniques is mentioned by Honea (1964:48) in his review of the English translation of Semenov. Semenov himself was *not* as firm a believer in experimental studies for edge-wear analysis as Sonnenfeld. Although he often used experiments and/or ethnographic evidence in his studies of function, he felt that the study of wear traces was sufficient by itself to determine use (Thompson 1964:x). He says this very clearly in several places; for example, in discussing wear patterns on sickles:

> Their traces of wear by disposition and microstructure are unmistakable and cannot be confused with any other type of work. Consequently precise definition of sickles is possible without experiments. The latter can merely show the efficiency of this or that type and test the character of the wear, but is not a method of defining the real function of ancient tools (1964:121).

In spite of his protestations, he relies on analogy with modern tools to arrive at hypotheses about uses represented by the various wear patterns he sees. Also, he uses experimental replication and use, followed by comparisons of wear patterns, to determine the kinematics of use for the tools in most of his classes. For instance, he describes experiments with sickles to determine their mode of use, as well as comparisons of wear on experimental and archeological specimens (pp. 121-122). Although Semenov's work was more systematic and more comprehensive than any previous edge-wear research, his contribution lies more in the recognition of the many variables which may affect edge-wear and in the technical advances in observing and recording edge-wear, than in a systematic application of experimentation to provide unequivocal statements about the influence of variables on edge-wear. Parenthetically, we can add that Semenov elevated the status of experimentation in his 1973 article, when he says "c'est uniquement la combinaison d' experimentation avec le methode traceologique qui donne de bons resultats dans la science (1973:110)."

A more rigorous use of experiment was provided by Keller (1966). Unlike Semenov's experiments, Keller's were not concerned with duplicating the edge damage found on a particular group of artifacts. Rather, he tried to investigate the factors which influence patterns of edge damage so that the results could be applied to tools from *any* archeological assemblage. Keller's experiments are well controlled and carefully recorded, and although he investigated a limited number of variables, his article provides a good model for such work.

In 1969 Tringham began an experimental program at the University of London in which she systematically repeated a large number of actions using flint on different materials, to arrive at information about the activities of the early Neolithic (Tringham 1971:145). The results of these experiments are reported in a clear and lucid description in Tringham et al. (1974). The latter is admirable for the thoroughness with which the experiments were conducted and the results reported, and for the large number of variables controlled for (see Table 1). In many ways this article is a milestone in the experimental application of edge-wear analysis. It is the first to systematically explore the effects of such variables as post-depositional treatment and number of strokes of use, and it is also innovative in setting up means of recording wear. The authors are also careful to give verbal descriptions of the wear which occurred at various stages of their experiments. They also provide high quality photomicrographs, as well as photographs of the experimental edge prior to any use; this controls for manufacturing scars and provides a background for measuring edge-wear (p. 184).

A good example of the fruitful use of experimentation and edge-wear is provided by Ranere (1975), who used these techniques to establish functions for an entire archeological collection. Ranere's method consisted of sorting through 45,000 artifacts with the aid of a hand lens and a binocular microscope, eliminating all unmodified, unused flakes. When he began to see patterns, in the form of recurring technological, functional, or stylistic attributes, he carried out experiments on replicated tools to reproduce these patterns. On the basis of his experimentation, edge-wear analysis, and comparisons with the archeological specimens, Ranere was able to identify the likely uses, class by class, of most of the tools of his collection. Although Ranere's experiments are not reported with as much precision as Tringham's, his contribution lies in the constant feedback between examination of wear on the archeological specimens and examination of that on the experimental tools. As the appearance of the wear patterns becomes closer, the likelihood of understanding how the archeological specimens were used increases.

Keeley has always been an advocate of the use of experimentation in edge-wear analysis. As he points out, experimentation is the only way we can control relevant variables and thus make precise statements about the causes of edge-wear (1974a:332). In 1977 Keeley and Newcomer performed an experiment of an experiment, in which they carried out independent tests of microwear analysis. Newcomer made 15 tools of Middle or Upper Paleolithic type, then used them in ways which would be compatible with this time period. After washing the tools, Newcomer gave them to Keeley, who, on the basis of microwear analysis, attempted to identify the uses to which the tools had been put. In 14 out of 16 cases Keeley was able to correctly identify the area of the tool which was used; in 12 of the cases he could reconstruct the movement of the tool; and in approximately 10 of the cases he could identify the material worked (Keeley and Newcomer 1977:59-61). The paper is a concise assessment of edge-wear research, which probably afforded encouragement to weary edge-wear analysts and perhaps convinced a few doubters that edge-wear analysis, when conducted with suitable controls, could lead to functional interpretations.

A modest but nonetheless exemplary contribution to the use of experiment in edge-wear analysis in determining function was Price-Beggerly's study of Hawaiian basalt scrapers. Commensurate with the trend towards controlling more and more variables, Price-Beggerly carefully noted the influence of the raw material, the techniques of manufacture, the material worked, the angle at which the tool was used, the number of strokes, and the mechanical action, on the wear on experimental specimens. Price-Beggerly was also innovative in her use of experimental controls, for she photographed and measured her specimens before they were used, then compared the specimens after use with these data and with unused control specimens to establish traces of wear (Price-Beggerly 1976:22-24).

Finally, an article by Brink (1978a) should be cited as a fine example of the use of experiment. Brink thoroughly and succinctly outlined his experimental procedure, in which he controlled for almost all variables which may have affected wear on his experimental specimens (1978a:365). It is to be hoped that this article marks the direction which future edge-wear studies will take.

INVESTIGATIONS INTO THE POSSIBLE CAUSES OF EDGE-WEAR

As Table 1 indicates, there has been a trend through time towards the investigation of a greater number of variables that may contribute to wear on the edges of stone tools. Earlier decades were characterized by studies that often quite casually investigated only one or two relevant variables. As interest in the field grew, however, researchers turned to increasingly rigorous control of a greater number of variables. Several recent articles have named and discussed the importance of studying these variables (e.g., Keeley 1974a; Odell 1975; Seitzer 1978); but it may be interesting to explore the way in which interest in them grew.

Mechanical action

It has long been recognized that the three-dimensional way in which a tool moves will influence which surfaces of the tool will be subjected to wear. Thus, for instance, Evans noted how certain "pointed implements" were held by the marks of wear on their edges (1897:655). Vayson claimed that by examining traces of use (i.e., polish) he could determine the material on which a stone tool was used, its mode of use, and even whether its use was slow or violent (1920:470-1, 1922:36). Much of Semenov's work is devoted to pointing out the "kinematics of wear" of various classes of tools by means of striations (1964:4). Because such striations are directional and task specific, he remarks (p. 6) that they are the most informative wear traces to study. Keller's experiments were designed to elicit the modes of use of stone tools. He held constant both the material from which the artifacts were made and the material on which they were used, varying only the mode of use (1966:501). Like Semenov, he concluded that in many cases "different modes of use produce characteristic patterns of edge damage (p. 507)." White was also able to distinguish between the actions planing, sawing, scraping, chopping, scraper-planing, and graving on the basis of macrowear (1968:515). Unfortunately, White only provided vague verbal descriptions of the wear he observed and failed to note what other variables were involved.

Most edge-wear experiments after 1973 were concerned with delimiting the kinds of wear which occur during various mechanical actions. A great deal of Tringham's experimental work was devoted to systematically testing the wear resulting from different actions. She subdivided the category "action" into 1) edge longitudinal to the worked material, 2) edge transverse to the worked material, and 3) edge/point highly localized and swung in a circular motion (Tringham et al. 1974:181). Keeley and Newcomer note that, on the basis of the examination of all wear traces (especially polishes), Keeley was able to correctly identify the kinematics of use of 11 of the 15 tools in their test (Keeley and Newcomer 1977:60). Finally, a recent study which is somewhat more peripheral to this subject is Odell's (1978) study of microlithic points, in which he used edge-wear to identify how the various point types were hafted.

The material of which a tool is made

The relationship of a tool's raw material to its edge-wear has engaged researchers nearly as long as the discipline has existed. Thus Moir puzzled over how a material as hard as flint could be scratched, concluding that patination softened the surface, making it much more vulnerable to striating (1914:177). Some 50 years later, Semenov was also concerned with this problem. He concluded that the formation of striations on flint, when flint was used on softer materials, was due to the introduction of small sand grains into the material being worked (1964:15). Although Semenov noted that striations may be variably apparent depending on the material from which the tool is made (p. 15), he concluded that striations are task specific, so that even differences in the material from which the tool was made cannot confuse conclusions about tool use (p. 6).

MacDonald and Sanger's findings several years later were not as reassuring, however. They maintained that observations relating to function could only be made on tools of softer stone (4-5 Mohs), while tools made of harder materials (6-7 Mohs) retained traces of manufacture (1968:237).

While most earlier experiments held the tool material constant and tested for other varriables, Brose's (1975) experiments included some in which he varied the lithology of his specimens and observed the length of time before the flakes became useless. He also did some experimentation with altering the properties of the raw material through pre-use heat treatment, an avenue which is surely a profitable one to explore (1975:88). Brose concluded with a significant thought relevant to this subject:

> Where large amounts of preferred raw material exist there are apt to be fewer observed striations, as there would be little need to exceed, or even approach, loss-of-function times. Where only a single lithic source is present, the amount of observable wear would be in direct proportion to the length of time involved in butchering (p. 93).

Aside from some experiments on obsidian (Schousboe 1977) and quartz (Broadbent and Knutsson 1975), most edge-wear analysis to date has been performed on flint. Keeley has found that his microwear polishes, first observed on English flint, are also visible on a fine-grained chert from Africa (Keeley 1977:126); but he notes that much more work is needed to discover if claims such as Semenov's are universally true.

The material worked

Because common sense dictates that the properties of the material upon which a tool is used will affect the wear on the tool, this variable has often been investigated. Perhaps the first explicit reference to its importance was by Vayson (1920:470-1), who claimed he could infer the kind of material upon which a tool was used by examining the polish on the tool. However, Vayson failed to back up his claims by experiment, and it was not until 1957 that any systematic tests of the significance of this variable were conducted. Nero was interested in the use of gravers found in Wisconsin; he manufactured a number of experimental tools and used them to incise lines on wood, bone, and shell. He was also concerned with mechanical action and found that while pulling the gravers across the surface broke the tip, pushing actions did not (1957:303). Although he failed to compare any wear on his experimental specimens with that on the Wisconsin gravers and contented himself with demonstrating *possible* uses, Nero provides us with an early example of the investigation of this third variable.

A good example of more recent research of this variable is Broadbent and Knutsson's 1975 study of quartz scrapers. Here they kept the tool raw material constant and studied the effects of such variables as material worked, number of strokes, angle of use, and edge angle. On the basis of 23 experiments they distinguished 3 types of wear resulting from use on hard fibrous materials, hard homogeneous materials, or soft, fatty materials (p. 122). Hayden and Kamminga also contribute to these studies by noting the density of the woods used in their experiments (1973:4). This enables other researchers to better reproduce their experiments on other materials of similar density.

Here again, the experiments of Tringham et al. represent one of the most thorough investigations of a variable, as they systematically tested materials from the hardest (antler, bone) to the softest (flesh, skin, plants). They stress that part of the aim of these experiments was to test Semenov's rank-list of materials from hard to soft (Tringham et al. 1974:183-4). Keeley, who has investigated this variable to its logical limit, claims that the "various worked materials such as wood, bone, hide, meat, antler, etc. produced distinctive microwear polishes that could be distinguished from one another at magnifications of around 200x (Keeley and Newcomer 1977:37)." If Keeley's claim is borne out by further experiments, then his results should be of great value to future edge-wear research.

Traces of tool manufacture

Although it was Semenov who first conducted large-scale and systematic studies of the edge-wear that arises in connection with tool manufacture, the difficulty of separating them from edge damage due to use has plagued edge-wear studies from their inception. As early as 1884, Spurrell was conducting knapping experiments and trying to distinguish between flakes removed by use and those removed during manufacture (1884:112). Semenov devoted a whole chapter in his original monograph (1964) to discussing his experiments with tool replication and to his attempts to separate wear due to use from that due to manufacture. Although he provided photomicrographs of the results of pressure flaking, he could offer no organized criteria for distinguishing manufacturing traces from wear traces.

An interesting article appeared in 1968, in which Frison examined tool resharpening. Frison's analysis of late prehistoric tools from Wyoming was a successful mixture of Bordes' ideas about bifacial retouch, Semenov's theories about edge-wear, and Jelenik's notes from the Les Eyzies conference on lithic technology (Frison) 1968:149). In a novel approach, Frison studied both tools *and* retouch flakes to arrive at conclusions about tool use and resharpening. Frison's paper is well-reasoned and carefully documented through photographs; and he finishes with a cautionary note which has often been disregarded in edge-wear research:

> It would appear that much time has been spent hypothesizing functions for tools tht were in a nonfunctional condition when recovered from their archaeological context. The same tool may also appear much different at different times during its life time of functional utility (1968:154).

In spite of this and other cautionary notes (e.g., MacDonald and Sanger 1968:237), Nance claimed, on the basis of striations along their edges, that "Stockton Points" may have been used as cutting tools rather than as projectile points (1971:362). This assertion was quickly seized by Sheets, a knapper, who pointed out that Nance was apparently unaware that pressure retouch often requires that the edges be abraded for platform preparation (Hester and Heizer 1973; Sheets 1973:217; cf. Keeley 1974b:127). Sheets (1973:218) describes criteria that can be used to distinguish use-wear from that due to manufacturing abrasion, thus performing a positive service for edge-wear analysis. However, Odell (1977:149) found it impossible to distinguish intentional retouch from wear on the basis of edge scarring. Instead, he classified any removal determined to have been of human origin as "retouch" and made further distinctions on the basis of edge and spine-plane angles.

A more recent paper on this subject is Brink's (1978b), who states that the carefully controlled manufacture of end-scrapers and their examination under the microscope enabled him to identify minute flake scars which were caused by manufacture, but which looked like use scars (1978b:31). More work like Sheets' and Brink's is needed to provide absolute means of differentiating these two sources of wear.

Edge angle

Recognition of the importance of the angle of the working edge began in the early 1960's with Sonnenfeld's attempt at designing a "bluntness index" for measuring edge taper on celts (1962:57-59). Although Sonnenfeld failed to note the effects of various edge angles on wear patterns in any more detail, the index shows his awareness of the significance of this variable and an attempt to standardize its measurement. Another profitable approach, which unfortunately has not been pursued, is Keller's practice of measuring flake cross-sections at intervals along the edge. Thus, the edge "migration" during use is reflected by increasing thickness. This method enables Keller to objectively record experimental wear (1966:502).

Wilmsen's (1968) article apparently had more impact on edge-wear research than did Sonnenfeld's or Keller's. Wilmsen's contribution lay in noting the kinds of edge-wear which can occur on tools of various edge angles. He integrated data from Semenov's work with his own from American Indian sites and from a collection of Eskimo tools. The chief weakness of this study lies in Wilmsen's liberally sprinkled hypotheses about the use of the tools he measured as he indicated neither the source of these hypotheses nor whether he tested them through experiment (cf. Lynott 1975:122). However, if one is content to see his ideas as hypotheses to be tested, or if one only uses his descriptions of the wear on tools in the various edge angle categories, Wilmsen's paper provides a basis for further research.

White's study of New Guinean stone tools revealed that the angle of the cutting edge was the most critical feature in deciding how a tool or flake was to be used (White 1968:513). Therefore, as the angle of the edge determines the function of the tool, it can be expected that edge-wear will differ among the different edge angle ranges. However, White notes that traces of wear can vary according to several other factors, such as the raw material of the tool, the wood on which it is used, the form of the tool, the length of time the tool is used, or the way it is used by each worker (p. 514). This last brings up a point to be taken up in the next section: the flexibility of the human hand and its ability to manipulate a stone tool during use. This characteristic affects the angle at which a tool is *held* during use (cf. Broadbent & Knutsson 1975:115), regardless of the edge angle of the tool.

Tringham was the first person to more systematically define this variable. She noted that although the degree of damage on a tool correlates with changes in what she called the spine-plane angle of the edge, the micromorphology of the scarring remains task-specific (Tringham et al. 1974:180). A more recent study in which the importance of edge angle was systematically studied was Broadbent and Knutsson's analysis of quartz scrapers. During their experiments they discovered which angles were the most useful for certain tasks; and they also noted a phenomenon they called edge stability, in which an edge that is not artificially retouched to within an ideal range for a task is naturally retouched through frictional use (1975:124). Keller (1966:509), Brose (1975:91) and Kantman (1970:273) also noted this phenomenon in their experiments.

Although many authors note the edge angles of the tools they study, there has been little systematic examination of the importance of edge angles to lithic edge-wear. An exception is Schousboe's (1977) study of random edge-wear on obsidian flakes, in which edge angles were controlled and the edge-wear of each category was noted.

The angle at which a tool is held during use

The position in which a tool is held with respect to the material on which it is used is exceedingly difficult to discover archaeologically. Mauser studied the effects of this variable in 1965, but little work has been done since then. While Mauser's work lacks a good discussion of microwear, it amply demonstrates the relationship between edge morphology, edge angle, and working angle during use. Semenov's emphasis on striations enabled him to recognize the angle at which a tool was held during its use (1964:17), and he sometimes included this information.

Gunn's (1971) paper is perhaps the most systematic study employing wear patterns to infer use angle. The location, and to some extent the appearance, of wear were used to infer the burin's working angle.

Many modern studies have recognized the significance of working angles in edge-wear analysis and have tried to keep these constant in experiments (e.g., Hayden and Kamminga 1973:6; Tringham et al. 1974:181; Broadbent and Knutsson 1975:115; Price-Beggerly 1976:23; Brink 1978a:365). But perhaps the only one to systematically examine this variable's importance is the Walker and Long (1977) study, in which the angle at which a tool was held was determined through an examination of the cross-section of the mark it made in bone.

One further variable which Odell alone has considered is that of damage from prehension. Through experiments and edge-wear analysis, Odell was able to distinguish many of the probable hafting and prehension positions for the tools in his archeological collection (Odell 1977:168-178).

Edge morphology

The morphology of the working edge of a tool must have some bearing on the location of wear on the tool. Although archaeological literature is replete with discussions of the limits tool morphology places on tool function, the question of the extent to which the shape of a tool's *edge* affects its wear has only recently gained recognition. One of the earliest and most systematic studies of this variable was by White (1969), who quantified edge morphology and studied the relationship between edge-wear and edge shape (1969:30). Odell discusses possible means of studying this variable, but he notes that "these variables of edge morphology are--like everything else in this subject--in their initial stages of analysis and concept formulation (1975:233)." However, a relatively early study of the subject (Mauser 1965) deals with the probable locations of wear, given various edge profiles; and the Harvard study (Tringham et al. 1974) also recognized the significance of this variable, trying to control for surface curvature and for edge protrusions in their experiments.

A novel approach to the study of edge morphology was developed by Walker and Long. They proposed "to develop an objective method for determining specific aspects of tool use and morphology from butchering marks that result from their application (1977:606)." By performing controlled experiments and examining resultant marks on bone caused by tools of differing properties, they were able to draw some conclusions about stone tool morphology, the pressure applied, the angle of use, and other variables which may reflect on edge-wear. In his dissertation, Odell (1977:132) distinguished between three elements of edge morphology ("curvature", "convexity-concavity", and "edge displacement") and proceeded to test edge-wear against these variables. In a project comparing tool classification based on edge-wear versus morphology, Seitzer (1978) included edge morphology as a variable and found some statistically significant relationships between edge morphology and edge-wear.

Wear due to post-depositional actions of nature

If one is to use edge-wear as a means of determining the functions of a stone tool, it is necessary to ascertain that tool wear is the result of its original use. Thus the researcher must be able to identify and factor out wear caused by the post-depositional forces to which the tool has been subjected (e.g., Keeley 1974a).

Semenov (1964:11) named abrasion by wind and water, weathering, and patination as possible natural causes of wear. Ten years later, Keeley (1974a:328) advocated that study pieces be compared with pieces that are known to have been subjected to the relevant natural processes, in order to best control for wear arising from natural causes.

The early work of Moir and Warren in examining possible natural causes of striations was discussed above in connection with experimental edge-wear analysis. Warren's experiments were particularly thorough when he tried to determine how much weight is necessary to striate flint with quartz grit (1914:441). He also discussed experiments designed to determine if the controversial eoliths might not have been naturally flaked.

Tringham's battery of experiments included one designed to test the results of water action on flints (Tringham et al. 1974:191). But by far the most comprehensive and the most useful paper on this subject was written by Stapert (1976). Stapert begins by noting that all phenomena mentioned in edge-wear literature as being caused by use may also be the result of natural processes (1976:8). He clearly and exhaustively describes the possible natural causes of each of these categories, providing means of differentiating striations due to natural agencies from those due to use (1976:20-28). While Stapert's paper should be basic to all edge-wear studies, it has received relatively little notice.

Wear due to post-depositional actions by man

Similar to the problem of naturally-attributable edge-wear is the identification of another type of wear not due directly to tool use. This unintentional wear is a result of human agencies, either aboriginal or by contemporary archaeologists. It would seem that recognition of the importance of this variable is confined to the past five years. For instance, the Harvard experiments included one in which 10 flakes were placed underground and "heavily trampled by members of the Peabody Museum for 30 minutes (Tringham et al. 1974:192)," to simulate post-depositional aboriginal wear. The lack of finesse of the experiment indicates the fledgling nature of this type of research; but apart from this attempt, little systematic work has been done in the area. Hayden and Kamminga also noted that the full complement of fracture types which Gould, Koster and Sontz had employed to define woodworking wear could be seen on unused adze flakes that were kept by their aboriginal informants in a bag at their shelter (1973:4).

More work has been done on controlling for wear caused by post-excavational handling by archeologists. In a provocative paper Briuer (1976) used microscopic examination and chemical reagents to identify organic use residues on stone tools. Briuer cautions that "archaeologists who religiously scrub their artifacts may be unwittingly destroying potential information bearing in the prehistoric function of the artifacts (1976:483)." However, Keeley claims that his microwear polishes withstand even chemical cleaning (1977:111). Wylie (1975) also cautions against vigorous scrubbing and against careless handling, labelling, and storage of lithic specimens which may destroy or confuse use-wear. Gero (1978) also tried to indicate what wear results when artifacts are subjected to typical post-excavational handling such as cleaning and screening, but her descriptions of wear are vague and unquantified. A more useful approach is seen in Schousboe's article (1977), in which he presents a series of experiments designed to provide edge-wear analysts with a means of distinguishing those fractures on obsidian which are due to random contact from those due to use. More controlled work like Schousboe's, perhaps on different materials, would be of great value to functional studies.

The length of time the tool was used

The importance of this variable is being recognized with greater frequency. Many earlier experiments measured the length of time a tool was used in minutes (e.g., Sonnenfeld 1962; Crabtree and Davis 1968; Kantman 1970, 1971), but it was Keller (1966:502) who introduced the idea that it was more accurate to measure the number of strokes performed by a tool. Keller was also a forerunner in the practice of taking photos of his experimental tools at arbitrary intervals during the course of the experiments, a practice continued by Kantman, Tringham, Broadbent and Knuttson, and Odell, among others. Much of Kantman's experimental work was devoted to this time factor, although he measures his results in terms of minutes. He noted that his experiments showed that it would require 20-30 minutes of work for an edge to acquire striations; but that as the tool could only be used for 10 minutes before becoming dull, the archaeologist would be unable to see any striations even though the tool had been used (1970:273). In another article Kantman describes the different use retouches which occur on tools used on different materials for various lengths of time, and he provides photomicrographs of many of these wear patterns (Kantman 1971).

It is clear that more experimentation is needed to quantify the effects of this variable, although Tringham et al. (1974:191) maintain that "it is *not* the case that given enough time all worked materials will eventually produce the same wear pattern." Only through controlled experiments will we be able to avoid the pitfalls noted by Frison (1968:154): "Care must be taken to determine whether two or more different-appearing tools are not the same tool, functionally, at different stages of use."

The force applied to a tool during use

Although experiments were being performed to investigate the effects of varying pressure on stone tool striations as early as 1914, little has been done since then. Warren's (1914) studies of eoliths indicated that quartz grit produced shallow scratching on flint under 6.4 - 9.0 kg of pressure, while 23 kg produced scratches that were deeper, although they were fewer and very short (1914:441).

It was not until the 1970's that this variable is again seriously considered. Several authors mention that they attempted to hold force constant in their experiments (e.g., Tringham et al. 1974:182; Broadbent and Knutsson 1975:116; Brink 1978a:365), but it is Walker and Long who first developed a means of actively exploring it. They used a Hansen platform scale to maintain a constant load during each cutting stroke and to measure the loads used to produce butchering marks (1977:606). Unfortunately, they note that "the estimation of pressure applied during a cutting stroke from groove depth should be attempted only when it is possible to control blade length (p. 612)," a condition not often fulfilled archeologically. Their experiments do indicate the importance of this variable, however: "Our experiments demonstrate that a variety of results can be obtained using the same tool at various pressures (p. 616)," and they provide an experimental means for testing the significance of applied force for edge-wear.

TECHNICAL ADVANCES IN EDGE-WEAR ANALYSIS

As both Keeley (1974a) and Odell (1975) have already provided discussions of advances in the techniques of edge-wear analysis, the following summary is brief and will concentrate on historical developments.

Quantification

Warren's work of 1914 is astonishingly progressive, since he not only quantified his experiments, but also devised a means of measuring the depth of the striations he produced in his experiments to the nearest thousandth of an inch (1914:441). Many years were to pass before such precision was again reached. Keller (1966), provided some linear measurements for the scars he produced through use (e.g., p. 507); and Frison (1968:151, 153) quantified the wear on his tools by the simple expedient of including a scale in mm on the photomicrographs he supplied.

Although Semenov's original publication lacks similar quantitative data, he was apparently aware of the need to do this. In 1970 he mentions a "micrometric method" to calculate changes in microrelief that are due to use, as well as a reflex technique to determine the degree of gloss in precise units (1970:8). It is unfortunate that he does not go into more detail about these techniques.

Very little progress has been made beyond these very simple beginnings. At best, authors have used micrometer scales in their microscopic examinations and have included linear measurements in their definitions of the edge-wear categories they use in their analyses (e.g., White 1969:26-27). The combination of careful verbal descriptions, including measurements and photomicrographs, has been the best means to date of standardizing edge-wear descriptions. As many have noted (e.g., Keeley, Odell, Seitzer), it is becoming increasingly urgent that a means of objectively recording edge-wear be developed so that results can be efficiently and accurately transmitted.

Until standard descriptions are achieved, it will be necessary for each author to define the categories used, or to give clear references to published descriptions used in order to avoid the confusion evident in publications such as Hester, Gilbow and Albee (1973:94). Ahler's study (1971) contains little quantitative data but does include extensive and thorough descriptions and photomicrographs of the categories used. The dispute between Hayden and Kamminga (1973) and Gould (1973) revolved in part around the formers' claim that the latter's definition of use wear was "imprecise and almost useless (Hayden and Kamminga 1973:3)." To remedy this situation Hayden and Kamminga included a glossary in their paper, in which they defined the types of wear they observed on the tools they studied. Some of the definitions include measurements in mm, as well as simplified drawings of the microwear fracture types they define. However, their definitions were at times rather vague, and it is unfortunate that the *Newsletter of Lithic Technology* had limited resources for photos. Also, as Gould points out, the practice of including measurements must be used discerningly, as the limits Hayden and Kamminga put on fracture size are so broad as to lack definition (Gould 1973:11). Keeley and Newcomer (1977:45) also include linear measurements in their definitions of wear categories, although their definitions are mainly based on nominal attributes.

Price-Beggerly (1977) makes reference to a quantitative technique which may be of potential value. She notes that before she began to use her experimental basalt scrapers she measured the working edges at arbitrary points and noted these measurement on a scale drawing of the artifact. After use she measured these points again and compared them against pre-use measurements. Apparently her technique requires refinement, as she found no measurable variations in size, even though during the use she observed minute particles of basaltic material on the worked surface (1976:22-23). It is unfortunate that Price-Beggerly does not describe her procedures in greater detail, as this may be a good means of measuring edge changes due to use.

One final advance in the field should be noted, namely, Keeley's techniques for recording the qualities of microwear polishes on a reflectivity graph (1977:116). By measuring reflected light in microamperes, Keeley quantified the brightness and smoothness of the microwear polishes he claimed could be used to identify on what materials tools were used. In combination with photomicrographs of these polishes, this provides a means for the identification of polishes.

Magnification

There does not seem to have been any chronological pattern in the amount of magnification which various researchers have found best for locating and identifying edge-wear on tools. As Keeley and Newcomer (1977:35) have surmised, differences here can be attributed to those indications of wear one seeks as being most diagnostic (1977:35). Thus, archeologists searching for microflaking (e.g., Rosenfeld 1971; Tringham et al. 1974; Odell 1975) find that low power magnifications are best; those who consider striations to be most important (e.g., Semenov 1964) deal mainly in middle-range magnifications (up to 100x); and those concerned with polishes (e.g., Keeley) use magnifications up to 400x. The debate about which of these wear indications is easiest to identify, but at the same time is most diagnostic has been going on for some time. The most reasonable approach seems to be the one adopted by Brink, who advocates "full consideration of all use-wear processes, and an appreciation of their interrelated nature (Brink 1978a:371)."

The earliest mention of the use of magnification in searching for wear traces was probably Quente's (1914:180) use of a magnifying glass to examine celts for wear. There followed a gap in which little mention is made of magnification until Semenov's monograph, with its thorough explanation of the use of a microscope in edge-wear studies and its myriad of fine photomicrographs, reached the English-speaking world in 1964. Although Semenov was not the first to study wear under the microscope, he was the first to do so systematically (Neustupny 1961:162), and he was also a pioneer in the use of higher magnifications (Tringham et al. 1974:172). Semenov advocated the use of a binocular microscope and magnifications up to 180x for most edge-wear analysis, but he noted that certain cases may require a monocular microscope and magnifications from 300-500x (1964:22). Semenov also provided a chapter on preparing surfaces for viewing and photography, a chapter which Keeley complains has subsequently been ignored in much edge-wear research (Keeley 1974a:324).

Despite Semenov's attempts at higher magnifications, most work done in the decade following his publication continued to use lower magnifications. Thus Gramsch made extensive use of the naked eye or a simple loop for observing striations, although he also employed magnifications up to 75x (1966:111).

White (1968:515) advocated that at least preliminary sorting be done macroscopically, since macroscopic traces of use can indicate to the archeologist if flakes were used and perhaps how they were used. This procedure is also less time-consuming than microanalysis. Rosenfeld discovered another limitation to microscopic analysis when she found that at magnifications above 80x the structure of the cherty flint she was studying was so coarse that it obliterated wear patterns on the edge (1971:177).

While some archeologists were debating the relative merits of macro- and micro-observations, others were beginning to realize the potentials of the scanning electron microscope for providing much higher magnifications than were previously possible. In a significant paper, Shiner and Porter (1974:284) noted that wear which may appear identical in ordinary photographs under low magnifications can show significant differences under the SEM at magnifications of up to 200x. However, not all microwear analysts were immediately enamored of this new breakthrough. Odell, for example, noted that micro-damage is also important for determining function, but that such wear may be missed if one concentrates solely on higher magnifications. He also notes that scanning electron microscopy requires coating and metallization of the subjects, a costly and time-consuming procedure which may obscure polish and abrasion (1975:230). A compromise solution may be analysis of the sort conducted by Pant (1976:9), who put primary reliance on the stereomicroscope but resorted to the SEM for problem cases.

A modification of these approaches is used by Keeley, who notes that a binocular microscope fitted with an incident-light attachment can be used within a range of 100–200x for making distinctions between microwear polishes on flint (Keeley and Newcomer 1977:36). This would seem to be a less time-consuming way of examing microwear at higher magnifications than the SEM. A compromise position of examination at lower magnifications to see the pattern and position of wear traces, and at higher to see wear polishes, may be the most profitable one.

Identification of residues

One recent advance in techniques for aiding edge-wear analyses should be mentioned, namely, identifying organic remains left on tool edges. Brose observed the presence of animal fats along the edges of his scraping tools because they fluoresced in ultra-violet light (1975:93). Briuer's paper (1976) provides means of identifying plant and animal residues on tool edges through microscopic identification and chemical analyses. Such results suggest that edge-wear analysts should avoid scrubbing those artifacts whose functions they wish to identify, and indicate exciting prospects for identifying the true functions of archeological specimens.

Photography

Long before Semenov demonstrated the use of photomicrographs to illustrate the wear patterns he saw and described, Moir was providing micro-photographs to illustrate his experiments with flint striations (1914: plate M). Although Moir failed to indicate at what magnification his photos were taken, he provided an early example of the technique whose importance becomes increasingly apparent in subsequent reports of edge-wear research. Curwen also experimented with microphotography and photographed the edges of flint sickles at 2x magnification to illustrate gloss (1930). However, it was once again Semenov who did extensive work with photomicrography at varying magnifications and who so richly illustrated his monograph with them. He also included a section on the photography of traces of wear. Although he was often careless about indicating the magnification at which objects were photographed, Semenov nevertheless provided the reader with a series of photomicrographs whose quality is still highly regarded. Semenov was also a pioneer in exploring the uses of stereo- and microstereo-photography for recording three-dimensional changes in tool edges (1964:27), and it seems curious that, aside from Campana (1977), more work has not been done in this field.

Sonnenfeld also illustrated his work with photomicrographs, which show a remarkable resemblance to some of Semenov's (compare Sonnenfeld 1962:62 and Semenov 1964:28, 131, 132). Like Semenov, Sonnenfeld failed to indicate the enlargement of the photographed celts, but he was careful to note the tool material, mechanical action, and material worked for the blades he photographed.

MacDonald and Sanger's paper (1968) was one of the first to provide practical hints on equipment, lighting and magnification for edge-wear researchers interested in photomicrography. In 1973 Sanger published a paper in which he supplemented earlier information and provided an alternative to photomicrography in the form of photomacrography for enlargements up to 40x.

A final technical advancement was described by Shiner and Porter (1974), who discussed the use of photography through a scanning electron microscope. They note that enlargements of pictures taken through a binocular microscope have almost no depth of field, while the SEM has enormous depth of field, so that even delicate wear is visible amid gross striations and ground edges (p. 286).

Aside from these purely technical advances, there have also been new developments in the use of photomicrographs in edge-wear research. Although Keeley complains that Western authors who use experimental copies of tools fail to examine them prior to use (Keeley 1974:328), there are some authors who not only examined, but photographed, edges prior to use (e.g., Keller 1966:502). Sheets also photographed the unmodified edges of his experimental tools prior to pressure flaking, in order to record the wear due to this manufacturing technique (1973:217-218). Lately it has become increasingly popular to use photographs of the unused edge as a means for comparison with subsequent wear on experimental specimens (Price-Beggerly 1976, Keeley and Newcomer 1977).

As recognition and control of variables has increased in the past few years, so has the practice of recording the progress of wear during experiments by means of photomicrographs of edges taken at arbitrary intervals. The Harvard study is an early example of this practice, which many subsequent authors have imitated (Kantman 1971, Broadbent and Knutsson 1975, Brink 1978a, Odell 1978). When authors are careful to note the other variables at work when the photo was taken, it is conceivable that such photomicrographs can be used as a basis for identifying the causes of edge-wear on other populations of artifacts.

CONCLUSION

Recent studies (e.g. Tringham et al. 1974; Keeley and Newcomer 1977; Brink 1978a; and Odell 1978), indicate that edge-wear analysis, once a struggling and uncertain discipline, is now becoming a strong and viable branch of archeological analysis. A trend begun in the 1960's towards increasingly rigorous experiments has resulted in more positive statements about tool use and the factors that contribute to wear on a tool's edge. It is to be hoped that many of the shortcomings about which Keeley (1974a) and Odell (1975) have chided us are gradually being corrected. I think the immediate goal of edge-wear research should be the construction of a general handbook, based on controlled experiments, which archeologists can use to identify under what conditions the observed wear on a particular artifact could have occurred.

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