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An experimental study of ground stone use-wear

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AN EXPERIMENTAL STUDY OF GROUND STONE USE-WEAR

by

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APPROVAL BY THESIS DIRECTOR

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ABSTRACT

This thesis is a study of some factors that influence ground stone use-wear. Experiments in ground stone technology provide valuable information that may strengthen behavioral inference. To understand ground stone use-wear, basic principles are borrowed from tribology, the science and technology of friction, lubrication, and wear. Four wear mechanisms relevant to ground stone wear are identified: adhesive, abrasive, surface fatigue, and tribochemical. Previous experiments tested the hypothesis that use-wear on experimental grinding implements varies with the material being ground. This study further tests the same hypothesis. Six identical mano/metate sets were manufactured and used by the author to grind five different substances: dried chokecherries, wheat, crickets, dried meat, and salt. The sixth tool set was used without an intermediate substance. Results tentatively validate the hypothesis. Several factors influencing ground stone use-wear are discussed and suggestions for future experimental research in ground stone technology are offered.

INTRODUCTION

This paper attempts to contribute to our knowledge of ground stone use-wear through tightly controlled experimentation. Previous experimental use-wear studies with ground stone, although indispensable for laying a foundation for future study, were not always tightly controlled. Some studies made use of archaeological specimens from museums (Zier 1981) while others employed implements manufactured specifically for experimental use (Adams 1988, 1989a, 1989b; Wright 1993). The present experiment takes the second approach by using identical mano/metate sets to grind a variety of materials. By maintaining control over as many variables as possible, it was hoped that differences in wear caused by grinding different materials or types of materials would be distinguishable.

The ultimate goal is not to define a methodology to determine what substances were ground in an attempt to decipher prehistoric diets, but rather to gain further knowledge of possible sources of use-wear variability so that inferences drawn from ground stone assemblages can be based on a firm understanding of what forms those assemblages (Schiffer 1987:7).

The notion that distinct wear patterns arise from use on different materials has long been a cornerstone of chipped stone tool microwear analysis (Keeley and Newcomer 1977; Keeley 1977, 1980; Lawrence 1979). Ceramic studies rely on that same broad hypothesis (Skibo 1992:4, 38-42). An analogous approach to ground stone artifacts is appropriate (Adams 1988:309).

Until recently, most studies of ground stone assemblages have been limited to mere description. Notable exceptions are 1) Bartlett's (1933) examination of changes in milling implement morphology and comparison of Hopi ground stone technology with archaeological manos and metates from northern Arizona and 2) Woodbury's (1954) discussion of both ethnographic and archaeological data from a regional perspective.

Beginning in the 1970's, numerous attempts were made to infer prehistoric behavior from ground stone assemblages (Gorman 1979; Zier 1981; Adams 1988, 1989a, 1989b; Horsfall 1987; Morris 1990; Schlanger 1991; Nelson and Lippmeier 1993). These studies range in emphasis from Gorman's (1979) information theory approach in which he treats an assemblage as a unit, to use-wear studies that emphasize individual artifacts as the basic unit of study (Zier 1981; Wright 1993).

Although the earliest studies in the behavioral approach to ground stone are valuable, they occupy a disproportionately small part of the published literature on use-wear, especially considering the abundance of ground stone in the archaeological record the world over. More recently, the work of Adams (1988, 1989a, 1989b, 1992), Fratt and Adams (1993), and Yohe *et al.* (1991) has contributed vast amounts of new information and numerous innovative analytical methods and approaches to the study of both ground stone assemblages and individual ground stone artifacts.

Experimental use-wear studies with ground stone, though few in number, are becoming increasingly important. Much information has been gained already through the work of Adams (1988, 1989a, 1989b, 1993), Mills (1993), Wright (1993),

and Zier (1981). The simple (or not so simple!) act of performing a task common in both the ethnographic present and in prehistory provides the researcher with a wealth of information on which to base further hypotheses and inferences. However, many ground stone use-wear experiments to date have been relatively informal. The current study attempts to maintain tight control over as many variables as possible in the grinding process.

The experimental manos and metates were manufactured from one type of sandstone; their sizes and shapes are similar; and the grinding position and technique were consistent throughout the experiment. Two of the manos were also used to pound as well as to grind. Use-time and material ground were the only significant variables. With this level of control, it was hoped that the following objectives could be reached.

Objectives

The primary goals of this research were to gain a deeper understanding of ground stone use-wear and technology and build on previous work by addressing some of the questions it raised. Adams' (1988, 1989a, 1989b) experimental work explored the possibility that processing different materials will produce unique wear patterns and concluded that differences were observable; she also pointed out the need for further testing.

In her analysis of corn grinding manos and hide working stones, Adams (1988) observed that while corn grinding produced scratches and crushing only on the tops

of grains, interaction of stone with a soft material (hide) resulted in less severe damage to individual grains but left a reflective sheen on the tops and sides of the grains. A wear pattern similar to the one on the hide processing stone was observed on a mano used to grind sunflower seeds (Adams 1989b:265). In the latter case, the difference was partly attributed to the superiority of the oily sunflower seeds as a lubricant between the stones. Although corn grinding predominantly caused scratching and crushing, the most worn parts of the corn grinding mano exhibited a sheen similar to that observed on the hide and sunflower seed tools. Adams (1988, 1989a, 1989b) attributes this wear trace to the interaction of oils in the intermediate substances with stone material and frictional heating released during grinding.

In an effort to build on the work discussed above, this experiment further tests the hypothesis that use-wear on milling implements varies both qualitatively and quantitatively with the material being ground; a corollary to this is that use-wear resulting from grinding soft and/or pliable material is distinguishable from that produced by grinding hard, brittle material.

SUMMARY OF WEAR PROCESSES

In order to infer behavioral patterns from use traces on ground stone artifacts, one needs an understanding of wear mechanisms and the processes that cause wear. Tribology--the science of friction, wear, and lubrication--provides information about friction and wear of materials. Most tribological literature, however, concerns industrial and engineering applications with metals, ceramics, and polymers. As a result, only the basic principles are applicable to archaeological situations. These will be defined and briefly discussed in an effort to build the proper framework for interpreting detailed use-wear analysis. These same processes and mechanisms will then be discussed in the context of how they operate on milling implements.

Recognition of tribological principles in archaeology is not new. Adams (1988:309-310, 1989a, 1989b, 1992) has discussed mechanisms of wear that affect ground stone tools. Schiffer and Skibo (1989) present a valuable synthesis of current knowledge of abrasive wear on ceramics. Finally, there is an extensive body of literature on the wear and wear processes of chipped stone tools (Hayden 1979; Keeley 1980; Vaughan 1985; Unger-Hamilton 1988; Sussman 1988; Graslund 1990).

Friction

Broadly speaking, the process by which wear occurs is friction resulting from the relative motion of two surfaces in contact. Friction is the resistance to the motion of two bodies sliding against one another (Bowden and Tabor 1956:1). In

order to understand how friction produces wear, it is necessary to understand the nature of the contact between two surfaces.

Nature of Surfaces. All surfaces, no matter how highly polished, are rough. There are high spots--asperities--and low spots--interstices. When two surfaces are placed against one another, they make contact only on the tops of the asperities. The location of this contact is termed the "real area of contact" (Arnell *et al.* 1991:21). The load, or weight, of one object resting on another is transmitted from the upper surface to the lower only through the real area of contact. The load causes pressure on the asperities, which adhere to one another through the creation of adhesive bonds on a molecular level. Adhesion contributes to the resistance to the motion of one body over the other.

Movement of the contacting surfaces creates a force strong enough to break the adhesive bonds between asperities. Adhesive bonds break at their weakest point, which may be at the point of contact between the two surfaces or in a weakness on one of the two materials (Arnell *et al.* 1991:32).

Further, when a force is applied it produces frictional heating, raising the temperatures of both surfaces. Quinn (1987:253) states that "...wear depends primarily on the temperatures generated in the contacting interfacial zones. These temperatures cause changes in both the micro-structure of the sub-surface regions beneath the wear track and in the chemical composition of the wearing surfaces."

By reducing friction, temperatures are lowered and wear proceeds more slowly. There are two ways to reduce friction: 1) surfaces can be designed to be

smoother and 2) lubrication can be introduced between the two surfaces. The latter is of interest to the current study, as materials ground between manos and metates act as lubricants (Adams 1989a:267).

Wear

Wear is the progressive loss of substance from a surface as a result of relative motion in contact with another surface (Arnell *et al.* 1991:66; Czichos 1978:98; Halling 1975:94). Four types of wear are relevant to ground stone use-wear studies: adhesive, abrasive, surface fatigue, and tribochemical (Adams 1988, 1989a:262, 1989b:260). The four processes are not mutually exclusive and, in fact, two or more processes almost always act in conjunction (Czichos 1978).

Adhesive Wear. As surfaces move against one another, the sliding, or tangential force breaks adhesive bonds between the two surfaces, releasing energy in the form of heat. As stated above, these bonds break at their weakest point. If the break occurs at the interface between two asperities, both surfaces remain unworn. If the break occurs within one body, there are two possible outcomes: 1) transfer of a wear particle from the damaged surface to the unbroken one through "cold welding", and 2) formation of a loose wear particle between the two surfaces. Even if the two implements are of identical hardness, particles may break off as a result of fatigue (see below).

Abrasive Wear. Abrasive wear occurs when 1) a hard surface slides against a softer one, resulting in removal of material from the latter and producing scratches

or striations; and 2) loose particles move between two rubbing surfaces resulting in further removal of material from one or both of those surfaces. Experimental studies show that abrasive damage is recognizable on ground stone surfaces (Adams 1989a:267). This process operates on both macroscopic and microscopic levels.

Surface Fatigue. Even with adhesive and abrasive wear mechanisms in operation, it is still possible for some asperities to come into contact without causing wear. In such cases, one or both contact points will be plastically and/or elastically deformed. After a number of such encounters, termed stress cycles, an asperity will fail owing to fatigue, and a wear fragment will result (Halling 1975:105). Like abrasion, surface fatigue occurs on both macroscopic and microscopic levels and is visible in the wear of milling implements (Adams 1989a:267).

Tribochemical Wear. The fourth wear mechanism relevant to ground stone technology is tribochemical wear. Czichos (1978:123-124) provides a succinct description of this process. Whereas adhesive, abrasive, and fatigue mechanisms operate primarily between two opposing surfaces in relative motion, tribochemical wear involves a third component, the environment. (In the case of grinding implements, the environment includes the substance being ground.) As opposing surfaces interact with each other and the environment, frictional heating causes reaction products such as oxide films to form on the surfaces. Continued rubbing removes the reaction products, producing loose wear particles and exposing fresh surfaces on which new reactions can occur. Residue build-up on ground stone tools is visible as

sheen (Adams 1989a:267). Sheen may also result from grain fracture and small scale abrasion.

Wear Traces. To indirectly determine the types of wear mechanisms in operation in a given situation, tribologists customarily study the worn surfaces for telltale signs that one or more of the mechanisms has contributed to wear (Czichos (1978:104). Each wear process produces distinct wear patterns that can be seen on ground stone surfaces (Adams 1989b:260-261). Whereas surface fatigue causes cracking and pitting, abrasion is mainly inferred from scratches, grooves, and striations. Adhesive and tribochemical wear leave cones, flakes, and pits; and reaction films and particles, respectively. Although it is important to understand the relationships of wear traces to the processes that cause them, identifying precise causal links between specific ground stone wear traces or patterns and particular tribological mechanisms is not crucial for this research.

Wear Rate. The concept of wear rate is extremely complex. Because tribological literature focuses on reducing wear of prepared surfaces on which asperity has been reduced as much as possible, it contains little of relevance to the wear rate of ground stone. In engineering applications, wear rate increases through time as wear increases the asperity of contacting surfaces. Milling implements are manufactured from naturally rough materials that are made rougher through manufacture. The asperity is reduced through use. Most important for the present study is the idea that the rate of material loss is proportional to surface asperity. All else being equal, more asperite ground stone surfaces are less stable than relatively

smooth surfaces and, as a result, wear faster. And, as wear progresses asperity decreases (in our case), causing a reduction in wear rate (cf. Schiffer 1979:18). Concomitant to a decrease in surface asperity is an increase in the real area of contact leading to a more even distribution of load.

An Archaeological Tribological System

With a basic understanding of tribological principles, it is possible to construct an idealized archaeological tribological system, in this case a set of sandstone grinding implements. For simplicity, the processes described are limited to a relatively coarse scale such as is discernible with low to medium power microscopy. By tribological standards, the wear processes described here constitute gross deformation of the tool surfaces. Undoubtedly, wear is also occurring at submicroscopic scales, but the main concerns of this study are the manifestations of wear processes that may be of help in interpreting behavior related to the use of grinding implements.

A set of grinding implements, whether a mano and metate or a pestle and mortar, has all of the components of a three part tribological system: two surfaces that contact each other in relative motion, and an intermediate substance. Because manos and metates are manufactured with rough surfaces (Bartlett 1933:4), they are prone to wear, especially resulting from stone-on-stone contact. Intermediate substances act as lubricants between the tools (Adams 1989a:267).

As a result of manufacture, when a mano rests on a metate, the real area of contact is only a fraction of the area of the smaller surface, the mano face. The weight of the mano is transmitted to the metate via contacting asperities. This holds true as the load is increased during grinding. The tools' resistance to wear depends on the ability of asperities to support the applied load without breaking.

In the case of a sandstone mano and metate set, wear will accumulate quickly at first as the processes of abrasion and surface fatigue cause grains on the highly asperite surfaces to break off. As the tool surfaces become smoother, wear rate decreases. Wear mechanisms still operate, but on a smaller scale.

The key to understanding ground stone use-wear is the recognition of wear traces resulting from material loss. The relationship of various ground stone wear traces to the mechanisms that cause them is not fully understood. Traces are undoubtedly produced by combinations of mechanisms.

Macroscopic wear traces include smoothing, sheen, striations, reduction in manufactured topography (pecking), reduction in natural surface topography, rounding, chipping, and loss of mass. Microwear is manifested as voids from grain removal, cracking, crushing, fracture, striations, sheen, grain flattening, and pitting not visible to the naked eye. These traces are discussed in relation to the experimental tools later.

BACKGROUND OF THE MATERIALS PROCESSED

Five materials were selected for processing based on archaeological and ethnographic evidence of their use with grinding implements by Native Americans in western North America. Dried chokecherries, wheat, roasted crickets, dried meat, and rock salt were selected. Another factor in material selection was availability and cost.

Chokecherries

Chokecherries were a common food of Native Americans in the West. There are numerous ethnographic references to their preparation, both fresh and dried. Most commonly the berries were pulverized on a mano and metate, and the mash formed into thin cakes for drying and storage (Robbins *et al.* 1916:47; Trenholm and Carley 1964:27; Downs 1966:19; Grinnell 1961:105, 1962a: 250, 1962b:177-178; Berthrong 1963:31). Alternatively, the berries were dried before being ground into a flour (Gifford 1941:95; Opler 1941:359). The latter method was used in the current study.

Wheat

There is, of course, abundant evidence, both ethnographic and archaeological, for grinding various seeds. In addition to cultivated species such as corn, wheat, and oats, numerous wild seeds were collected and ground. Elmore (1943) provides a

comprehensive list of wild seeds used by the Navajo for food, and Chamberlin (1911:339-343) presents a brief discussion of the collection and processing techniques employed by the Gosiute of northwestern Utah. Because it is easily available, wheat was selected as a suitable seed for this experiment. However, it is not considered to be a substitute for future experimentation with wild seeds. The wheat ground in this experiment was raw and hulled.

Crickets

There are numerous ethnographic references to the role of insects in hunter-gatherer diet. Most of these references in the western United States describe the collecting of grasshoppers, ants, or crickets by groups in and around the Great Basin (Steward 1938:34; Lowie 1924:195; Kelly 1932:90-91, 93). Most commonly, crickets and grasshoppers were gathered into a large fire by means of a drive that surrounded an area where the insects were known to be abundant. Alternatively, they were simply collected by hand from shrubs. The latter technique worked in the early morning hours when the crickets were too cold to be active. After collection, the insects were roasted and dried, and then ground into a flour or paste (Trenholm and Carley 1964:6; Lowie 1924:195; Riddell 1960:36-37; Fowler *et al.* 1969:26; Henderson and Harrington 1914:58; Downs 1966:35). The crickets for this experiment were purchased from a cricket ranch.

Dried Meat

Another common use for ground stone tools was the pounding and/or grinding of dried meat. Dried venison is the meat most often referred to in the ethnographic literature of the Southwest and Intermountain West. It was prepared by pounding and grinding until it was sufficiently pulverized to add to soups (Smith 1974:48; Grinnell 1962a:256; Gifford 1941:98-99; Steward 1941:333; Stewart 1941:376, 1942:253). Small animals such as rodents were also processed with milling implements on occasion (Cushing 1920:599-600; Yohe *et al.* 1991). A variety of different meats were dried and ground for this study. Beef was the most common, but elk, antelope, lamb, and turkey were all used. The meat was thinly sliced and dried in a dehydrator.

Rock Salt

The last intermediate substance chosen for the present study is salt. As with the other materials, there are numerous ethnographic references to salt grinding. The western Apache collected salt in the form of stalactites from caves in the Salt River Canyon and ground it with metates and manos (Gifford 1941:96-97). The Tepehuan of Chihuahua traded with mestizos for salt in lump form. This was ground several times on a metate before it was used (Pennington 1969:99). Salt was also a common resource for many Great Basin groups, who either traded for it or collected it from natural deposits (Steward 1941:333; Stewart 1942:337). For this study Morton rock salt for water softeners was ground.

EXPERIMENTAL PROCEDURE

Tool Design

Six sets of manos and metates were manufactured from two pieces of sandstone from the Lyons Formation on the Colorado Front Range of the Rocky Mountains. Sandstone is a common material for ground stone implements recovered from the archaeological record. The stone for this experiment was selected on the basis of gross visual similarity to materials observed by the author during field work in northwestern Colorado. Manos were all cut from one slab, metates were cut from the other. A small sample of stone from each metate underwent petrographic analysis by Beth Miksa at the University of Arizona. A detailed description of the stone is presented in Appendix A. The tools were made of a rose pink, fine- to medium-grain, bedded sandstone. Its composition is 90% quartz, 5% feldspar, and 5% other lithic material. The grains are round to subround and range from .125 mm to .4 mm in size. There is little to no cementing material. Instead, the grains have been pressed together under great pressure; some grains wrap around others. Porosity is approximately 15-20% and the pores are as large as the quartz grains. All implements were made from stone from the same formation in order to control for variable wear resulting from differences in stone texture and hardness.

All metates were the same size and shape, as were manos. Each metate measured approximately 30 cm x 20 cm x 6 cm. Manos were approximately 12 cm x 7 cm x 8.5 cm. The manos were originally cut into oblong blocks; then the long edges

were beveled at a 45° angle so the ends of the manos are octagonal. The consistent tool sizes helped control for variability in motor habits; similar tools are likely to be used in similar fashion and experience similar forces during use.

After initial cutting, the use surfaces of both the manos and metates were roughened (pecked) with an electric hammer drill using a steel carbide masonry bit to roughen the tools. Individual peck marks ranged from <1 mm to approximately 2 mm deep. An unpecked border was left around the edges of the metates. The border was approximately 3 cm wide along lateral margins and 4 cm wide on the ends. Manos were pecked on one of the narrower original faces and on both adjacent beveled faces. The ends of four of the manos were rounded with a hammerstone before grinding to make them more comfortable to hold. The control mano (#6) and the chokecherry mano (#1) were not rounded on the ends.

Tool Use

The six mano/metate sets were numbered and #'s 1 through 5 were each used to grind one of the five materials discussed above. The sixth set of tools was used as a control without an intermediate substance.

tool set #1-chokecherries (28 hours, 7 minutes)
tool set #2-wheat (20 hours, 8 minutes)
tool set #3-dried crickets (3 hours, 53 minutes)
tool set #4-dried meat (4 hours, 26 minutes)
tool set #5-rock salt (15 hours, 57 minutes)
tool set #6-no intermediate substance (15 hours)

To perform the experiment, metates were placed on a table about 5-7 cm back from the edge. The author sat in a chair in front of table and, with the exception of mano #6 and a short period with mano #1, held the mano with both hands, fingers around the ends and thumbs supported on the proximal face and top of the tool. Mano #6 was used both right- and left-handed and with both hands, but use was predominantly the latter. One-handed use of mano #1 lasted well under ten minutes, as it was difficult for the author to keep the chokecherries on the metate when grinding with one hand.

Emphasis was placed on comfort and efficiency. The grinding posture provided a fair balance between the ability to move the mano back and forth across the metate and to exert downward pressure. No deliberate attempt was made to imitate methods described in the ethnographic literature. The goal was to grind whatever material was on the metate as efficiently as possible without consciously hurrying.

When metates moved around under the pressure exerted, they were anchored in place. Although grinding was performed in two different settings, the position and technique were held virtually constant throughout. Only the author used the tools.

Data Recording

Length, width, and thickness was measured for each tool to the nearest millimeter before and after the experiment. Tool masses were measured to the

nearest gram both before and after grinding. Complete metric data are presented in Appendix B.

Before grinding, a coarse measure of surface topography was made and drawn with the aid of a carpenter's contour gauge for four transects on each tool use face (Figure 1). Subsequently, the same transects were redrawn after approximately every four hours of grinding. The purpose of these profiles was to measure changes in gross surface morphology caused by grinding. Profiling quality varied considerably from the beginning to the end of the experiment and no profiles were taken for the control tool set (#6), which was ground first. Because this aspect of data collection was inconsistent from one tool set to the next, the profiles are of little interpretive value. Only the mano profiles changed significantly, but the variable quality of the profiles makes them unreliable. A similar approach would be a valuable source of information for studies in which grinding is done for multiple use-episodes and resharpenings.

All the tools were photographed before the experiment. Close-up photographs of tool use-faces and overview photographs were taken to record macroscopic features of the unused tools. Photomicrographs of analysis locations for each tool were taken at 32X and 80X to show pre-grinding microscopic characteristics.

Input/Output and Time Data. To monitor grinding efficiency differences, unground intermediate substances were measured out into bags of approximately 150 grams each. The bags were numbered and the approximate volume of each bag was recorded. Each material had its own numbering sequence. Only one bag was

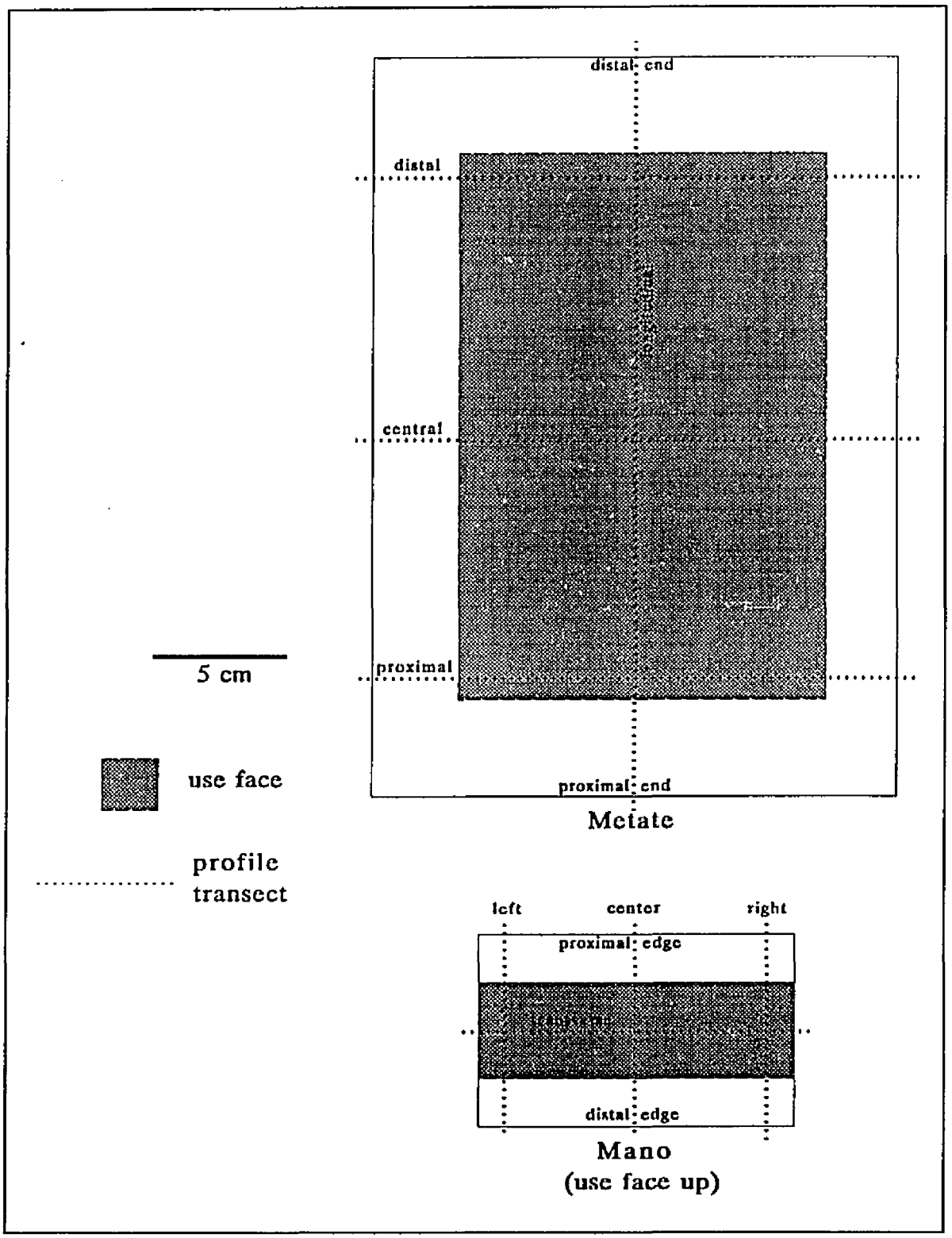


Figure 1 Locations of profile transects

ground at a time. Grinding time and post-grinding volume and mass per 150 gram bag were recorded. The total amount of each intermediate substance ground was recorded, as was the total use-time for each set of tools. Appendix C presents complete input/output and time data. Occasionally, informal analyses of the tools were performed and observations were written down. General thoughts concerning subsistence, grinding technology, energy expenditure, and other pertinent insights were also recorded.

Analysis

After grinding for the number of hours and minutes listed above (page 23), each set of tools was rinsed with warm tap water and subjected to three stages of analysis. The first stage was macroscopic inspection of each tool and description of use-wear traces. Overall tool morphology was noted as well as specific use-wear traces.

The second stage of analysis was microscopic. Five locations on each metate and four on each mano were examined under a stereomicroscope at 16X and 40X magnifications. Each location was centered on a specific point on the tool use-faces. The various points were chosen so differences in wear distributions, if present, could be observed across tool surfaces. The locations were the same for each tool set (Figure 2). The sizes of analysis locations varied with magnification. The lower of the two magnifications examined areas approximately 14 mm in diameter. The higher magnification areas were approximately 5 mm in diameter.

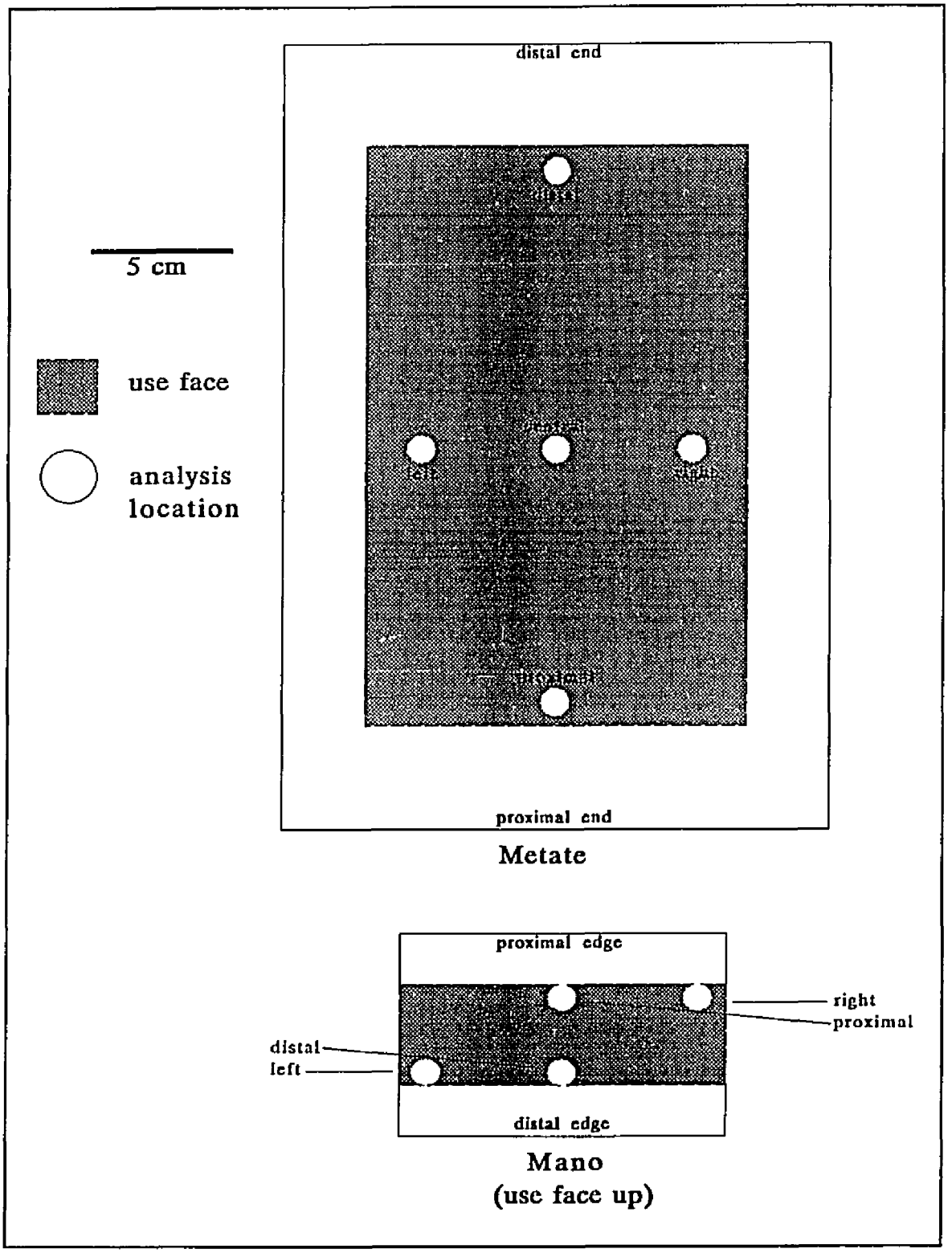


Figure 2 Locations of microscopic analyses

The experimental tools were photographed macroscopically and microscopically both before and after their total use-times. Macroscopic photographs show approximately a 12 cm x 8 cm area for metates and a 7.5 cm x 5 cm area for manos. Reduction in the field of view caused photomicrographs to be taken at 32X and 80X instead of 16X and 40X used in the second stage of analysis. The large discrepancy between the second stage analysis magnifications and those used for photomicroscopy prompted a third stage of analysis.

The third stage, like the second, studied microwear but used the same magnifications as the photomicroscopy. This tactic, especially 80X examination, proved to be particularly informative. The analysis locations used during the second stage of analysis were ignored during the third stage. Instead, a less structured analysis was done that focused on comparing diagnostic areas on the different tool sets.

A final step in the experiment was photomicroscopy with a scanning electron microscope (SEM) at 80X. One location representative of the most intensive wear (as indicated by smoothing and sheen) on each metate was cored with a diamond bit with a 2.3 cm inner diameter. Photomicrographs were taken near the center of the ground face of each core.

RESULTS

The experimental tools were used for a total of 72 hours, 31 minutes to grind 47.8 kg of material (Table 1). The experimental results tentatively validate the hypothesis and its corollary. Qualitatively and quantitatively different damage patterns were observed. Some qualitative differences appear to have resulted from grinding different materials. Before discussing the differences, however, some setbacks encountered during the experiment must be mentioned. These problems do not seriously detract from the main goal of the project and their recognition will strengthen future ground stone research.

Table 1 Mass and volume data for materials ground

material	volume(ml)	mass(g)
chokecherries	11,065	6,793
wheat	9,975	8,550
crickets	12,000	3,509
dried meat	*3,000	3,004
salt	21,625	25,950
totals:	57,665	47,807

* Estimate based on displacement in ml of 50 grams of dried meat immersed in water.

The first problem was lack of control for use-time. It was originally intended that tool sets would be used until sufficient wear accumulated for analysis to be informative. In fact, all tools were used to that extent. Some tools, however, were used far beyond that, making meaningful comparisons of wear rate impossible. Use-times (page 23) ranged from almost four hours to over 28 hours. As a result, discussion is limited to different *types* of wear.

As Schiffer (1979:18) has hypothesized in relation to microwear studies of chipped stone tools, wear types are inextricably linked to use-time. On the control

tools (#6), for example, the relative importance of grain removal, fracture, cracking, crushing, and fine abrasive smoothing and polishing changed throughout its use-episode (use-time between resharpenings). Wear proceeded quickly at first, slowing progressively as the surfaces became less asperite and, hence, more able to withstand the applied load. Wear traces on roughened, "sharp" tools included voids, cracking, fracture, and sheen on fractured grain facets. As the tools approached the end of their use-episode, the use-traces of grain flattening, striations, sheen, and pitting predominated.

Another problem was the failure to recognize at the outset the potential costs and availability of two of the substances ground. The cost of meat sufficient for grinding 20 hours (the same amount of time as wheat) was prohibitive. There are alternatives to buying meat, but they were not explored. Crickets posed a similar problem, though the expense was considerably greater. Twenty hours of grinding would require approximately 56,650 crickets worth approximately $500.00. An alternative to purchasing crickets would be to harvest them, a project that would require extensive planning and a budget of its own. In the future these costs need to be weighed against their potential for providing valuable sources of information. These oversights resulted in comparatively short use-times for the cricket and dried meat grinding tools.

During the experiment, it became clear that the tools were designed poorly. Metates were too small relative to manos and the pecked areas on the metates were too large relative to their overall size. These design flaws decreased grinding

efficiency because intermediate substances fell off the metates before they were properly ground and had to be swept up and put back. Had the metates been larger relative to their pecked areas and relative to the manos, less material would have "slopped" over and efficiency would have been better; less time would have been spent grinding similar amounts of material. In addition to size, the depth of a metate basin or trough undoubtedly influences grinding efficiency. Deeper basins and troughs better contain the material being ground.

Macroscopic Use-wear

Macroscopic analysis focused on gross surficial modification. Macroscopic wear traces include smoothing, sheen, striations, reduction in manufactured topography (pecking), reduction in natural surface topography, rounding, chipping, and loss of mass. Most of these traces were found on all of the tools. Three exceptions are striations, rounding, and chipping, which were only observed on a few tools.

There were, of course, many similarities in use-wear patterns between the experimental tools. Regardless of material ground, topographic highs were invariably worn smoother than lows and on all tools at least some areas exhibit sheen. This was expected as high spots are more subject to stone-on-stone contact. All tools suffered loss of pecking and reduction in natural surface topography. Finally, all tools experienced loss of mass.

Loss of mass is the only quantitative measure of wear (Table 2). Figure 3 shows the relationships between percentage of mass loss and use-time for the six tool

Table 2 Tool mass data

tool set	material ground	metates before	metates after	metates %loss	manos before	manos after	manos %loss	%loss for set
1	chokecherries	8,999	8,957	0.47(2)	1,572	1,550	1.40(3)	0.61(2)
2	wheat	8,990	8,953	0.41(3)	1,612	1,596	0.99(5)	0.50(3)
3	crickets	9,115	9,087	0.31(5)	1,636	1,624	0.73(6)	0.37(6)
4	dried meat	9,304	9,282	0.24(6)	1,604	1,574	1.87(2)	0.48(4)
5	salt	9,161	9,131	0.33(4)	1,604	1,588	1.00(4)	0.43(5)
6	control	9,424	9,349	0.80(1)	1,704	1,669	2.05(1)	0.99(1)

Numbers in parentheses indicate ranking of %loss.

sets. The control set lost by far the most mass even though it was used for a much shorter time than either the chokecherry or wheat tools. This clearly shows that stone-on-stone contact wears grinding tools faster than other types of contact (with intermediate substances, for instance). It also indicates that the materials ground reduced wear rate by acting as lubricants.

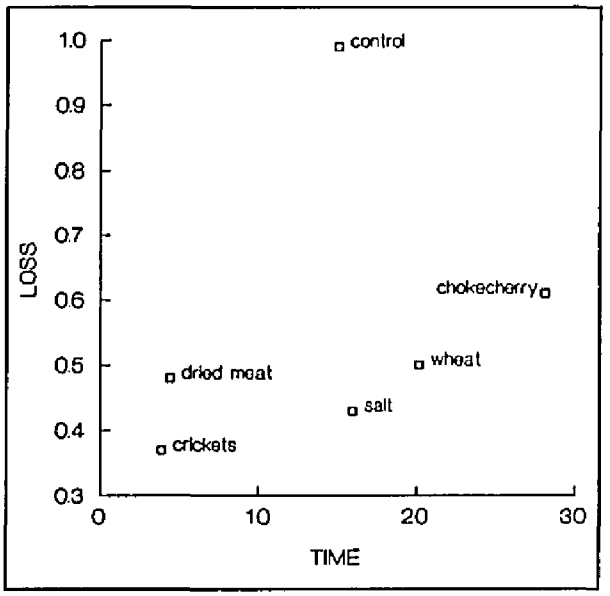


Figure 3 Relationship of use-time to percentage of mass loss

For the other five tool sets, material loss correlates fairly well with use-time. An exception is tool set #4, which was used to pound and grind dried meat. The pounding caused significant material loss from the use-end of the mano in a relatively short time. The chokecherry mano (#1) probably lost a similar amount of

material pounding chokecherries, but this is obscured by the fact that its ends were not rounded for comfort before use. Spearman's rank correlation coefficient was run for the five tool sets used to grind intermediate substances (Gibbons 1985). Results showed that R=.9, with a P-value of .042, rejecting the null hypothesis and indicating a statistically significant association between use-time and percentage mass loss.

Two factors compromise the value of mass loss measurements. First, the ends of four of the six manos were rounded prior to use to make them more comfortable to hold, so material loss resulted from both manufacture and use. The ends of the chokecherry (#1) and control manos (#6) were not rounded and their angular ends made work painful. The ends of the other four manos were minimally rounded by pecking in the places where they fit into the palms of the hands. Another source of potential inaccuracy in the mass measurements is the presence of residues from the materials ground. The stone used for the experiment is quite porous and oils from chokecherries, crickets, and meat were absorbed. The amounts of residue absorbed cannot be measured, but undoubtedly offset material loss, however minimally. The potential for identification of residues other than pollen on grinding implements has only recently been explored (Yohe *et al.* 1991). Skibo (1992:40, 85-101) describes analysis of residues from ceramic sherds and much of his approach may be directly applicable to ground stone artifacts.

The degree to which use-traces other than loss of mass affected the tools was measured subjectively. Figures 4a and 4b show close-up photographs of representative metate and mano surfaces before grinding. A comparison of the tools after use

shows that the control set (#6) has by far the most use-wear (Figures 4c and 4d). Both mano and metate lost most of their pecking and a significant amount of natural surface topography was smoothed. Every kind of wear trace was observed. Evidence of sheen was striking; frictional heat generated during grinding suggests the operation of tribochemical mechanisms, but it is likely that abrasive wear also played a major role. The rock powder produced during stone-on-stone grinding acts as a fine abrasive. At the same time, frictional heating probably helps form reaction products on the tool surfaces. This was the only tool set on which macroscopic striations were observed, a clear indicator of abrasion.

Wear distribution is not uniform across tool surfaces. On the metates, distal and proximal locations were less prone to heavy wear than central and lateral locations. The relative sizes of the metates and manos necessitated a limited reciprocating grinding motion in order to keep the intermediate substances on the metates. By concentrating short strokes in the center of the metates, less material fell off and grinding was more efficient. Accordingly, wear is most severe in the centers of the metates. Lateral locations wore nearly as fast because the experimental manos were only a little narrower than the pecked use areas on the metates. Lateral fluctuations in the grinding stroke caused the entire width of the metate use-areas to be worn.

Wear distribution on experimental manos was most severe along the junction of the distal beveled face and the use-face. In some cases the edge became rounded enough to obscure the original angle where the two faces joined. As with the

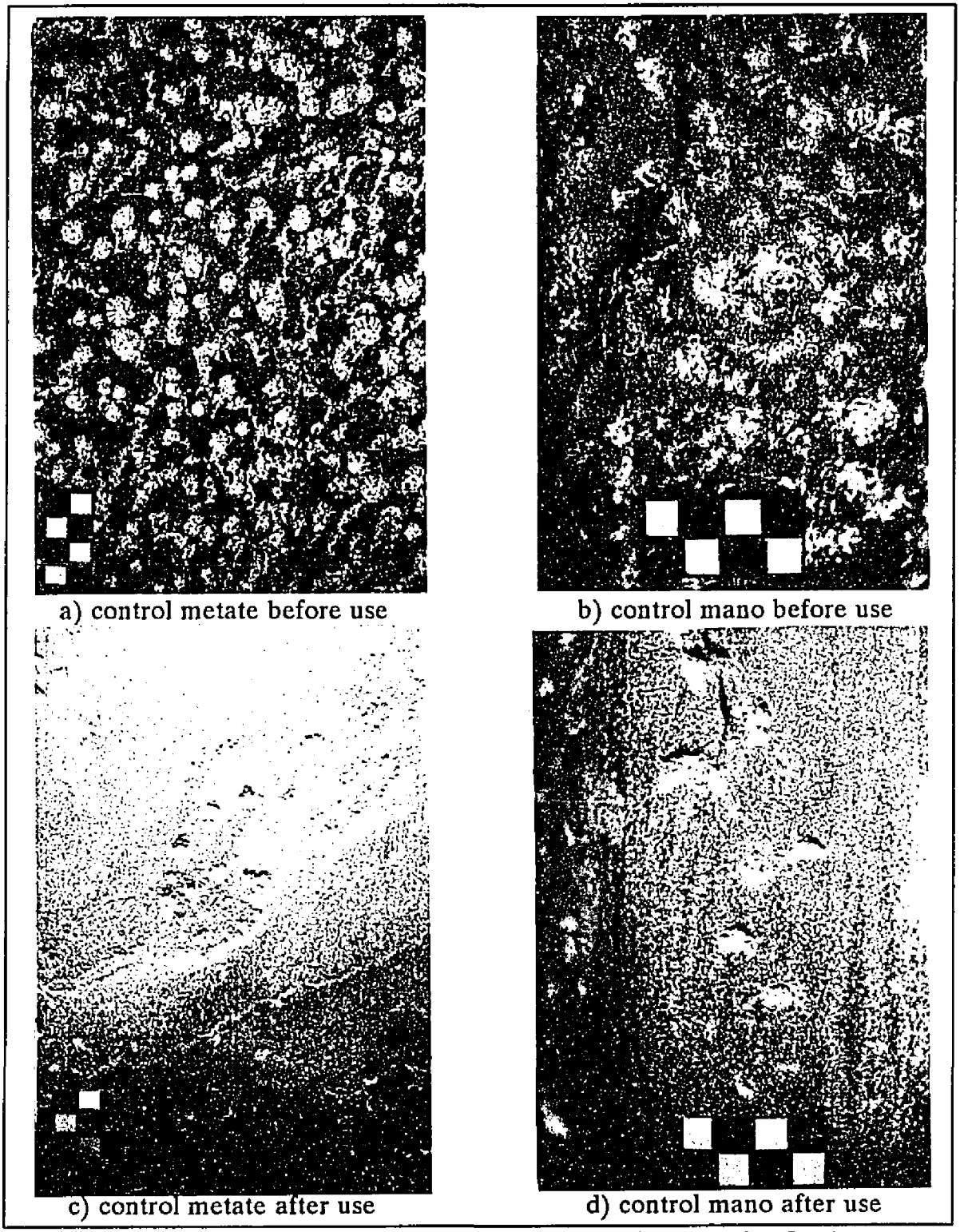
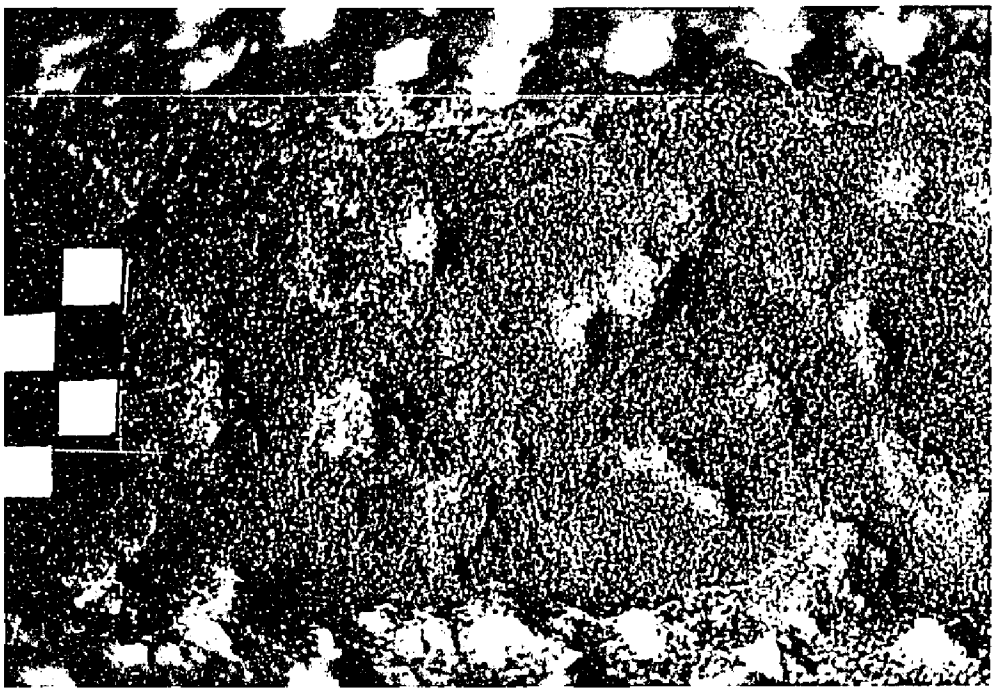


Figure 4 Control set (#6) before and after 15 hours of use (scale=2cm)

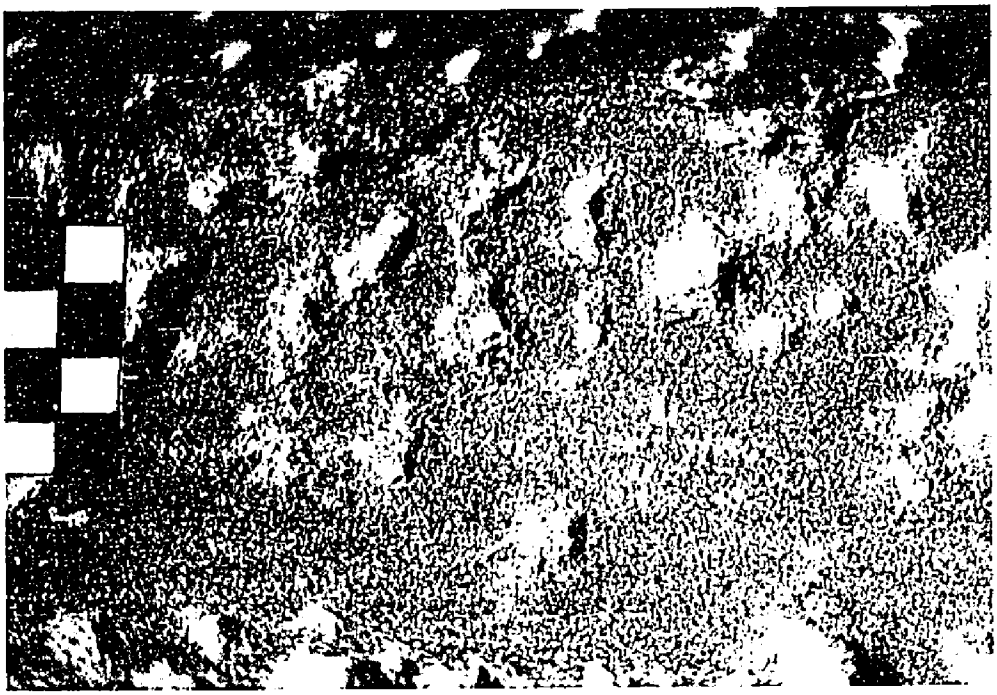
metates, wear is most severe where work load was highest. Interestingly, wear intensity as indicated by edge rounding is partially independent of use-time. For example, the cricket grinding mano, used for 3 hours, 53 minutes, is distinctly more rounded on its distal edge than the mano used on chokecherries for 28 hours, seven minutes (Figure 5). This is because the crickets allowed more stone-on-stone contact between the mano and metate than the chokecherries. All of the mano use-faces were at least slightly convex after grinding. The use-face of the control mano was indistinguishable from the beveled edges after use.

With the exception of the metate used for crickets, none of the metates experienced any change in overall surface shape. No basining or troughing occurred. In fact, the control metate (#6) was the only one with significant reduction in natural surface topography. The distal end of the cricket metate (#3) was used to help scrape the mano clean periodically to maintain efficiency. It became slightly rounded and chipped as a result.

For the five tool sets used to reduce materials, wear variability can be partly attributed to differences in use-time. Wear rates of the experimental tools are probably determined in large part by the ability of the intermediate substances to act as lubricants, but this cannot be reliably compared because of the wide range of use-times for the different tool sets. Clearly, there are macroscopically identifiable qualitative differences in wear patterns attributable to differences in the material ground.



a) chokecherry mano (#1) after 28:07 of grinding



b) cricket mano (#3) after 3:53 of grinding

Figure 5 Chokecherry (#1) and cricket (#3) manos after use (scale=2cm)

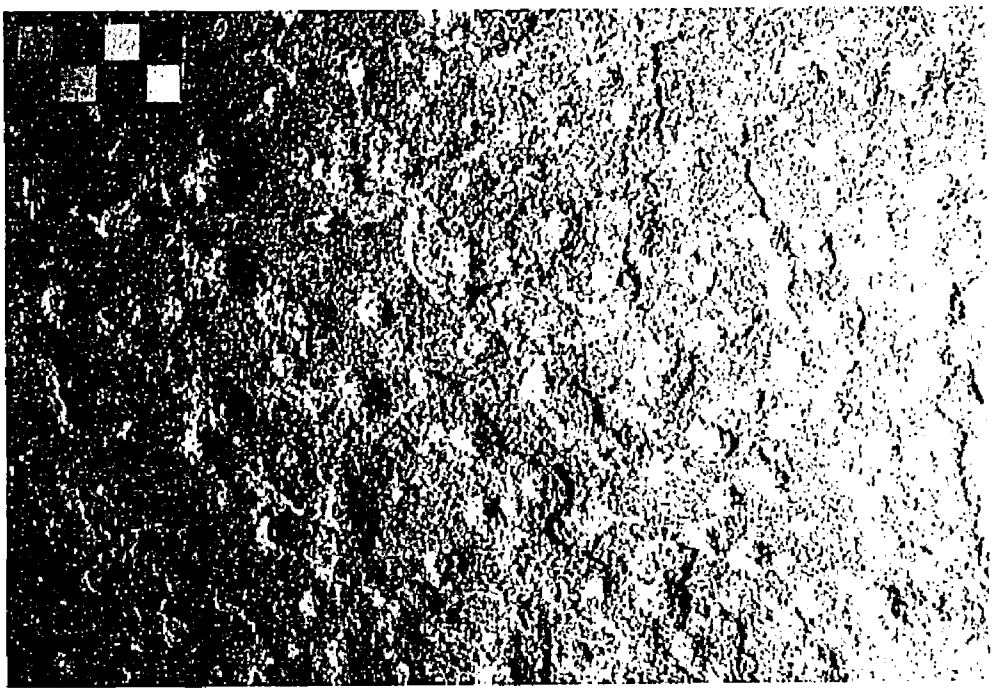
The chokecherry tool set (#1), which had the longest use-time, retained almost all of its original topography with sheen visible only on topographic highs. While chokecherries produced less wear overall than stone-on-stone grinding, the wear extended more deeply into some topographic lows on the metate (Figure 6a). Wheat had a similar effect, though less well developed. This was not the case for the salt grinding metate (#5), on which wear was limited predominantly to topographic highs (Figure 6b). Interestingly, the absence of pecking on the chokecherry metate (#1) was the only significant macrowear trace in low areas; smoothing was minimal and sheen absent, suggesting that extensively worn surfaces may not always be recognizable by the unaided eye on archaeological ground stone fragments.

The metates used to grind crickets (#3) and dried meat (#4) expectably suffered the least overall macroscopic wear. Their surfaces experienced well developed smoothing and sheen on topographic highs, but pecking was not significantly reduced and topographic lows suffered little to no damage.

Microwear

Differences in microwear patterns are influenced by several interrelated factors. As with macrowear traces, uneven work loads at different locations on a single surface caused variability in microwear traces. Natural surface topography also influenced microwear, with depressions experiencing less damage than topographic highs. Finally, different intermediate substances caused variability. The combined influences of these factors with use-time resulted in distinct patterns on the experi-

a) chokecherry metate (#1) after 28:07 of grinding



b) salt metate (#5) after 15:57 of grinding

Figure 6 Chokecherry (#1) and salt (#5) metates after use (scale=2cm)

mental tool surfaces. Unlike macroscopic wear patterns, manos do not exhibit different microwear than metates.

The magnifications used for the various analyses proved to be appropriate. The lowest magnification, 16X, was valuable for assessing how microwear traces combined to influence the overall appearance of tool surfaces. However, informal experimentation with different magnifications showed 10X to be even better. In addition, crude striations were only discernible under low power magnification. In contrast, 80X highlighted wear traces on individual grains. The two intermediate magnifications (32X and 40X) were not significantly different from one another, but provided a middle scale for analysis.

Microwear traces are described and related to wear mechanisms in Table 3. The definitions are presented for two reasons: 1) to provide a framework within which wear on the experimental tools can be described and 2) to begin a dialogue with other researchers for the purpose of refining the terminology used in ground stone wear description. Just as Schiffer (1979:18) called for standardization of terminology used for chipped stone tool wear, there is a similar need for standardization of methods and terminology in ground stone wear studies. Indeed, it is entirely appropriate to work toward defining a use-wear lexicon that combines elements of tribology with chipped stone, ground stone, and ceramic studies.

As with macrowear traces, the differences between tool sets are a matter of degree, and wear patterns change *in situ* during the use-episode of a tool. In looking for differences between tool sets, I tried to partially mitigate the effects of use-time

Table 3 Microwear traces observed on experimental tools[1]

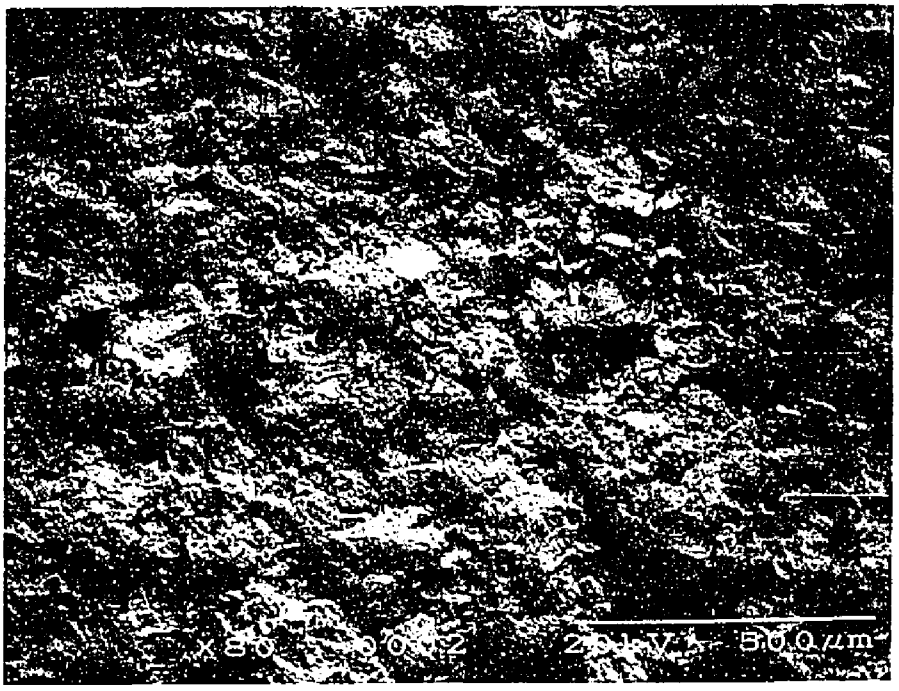
trace	description	wear mechanism(s)[2]
voids	depressions or interstices between grains: can be confused with natural pores	removal of whole or partial grains by surface fatigue and abrasion
cracking	cracks extending into surfaces of individual grains; sometimes many cracks are interconnected	surface fatigue; grains unable to withstand repeated stress cycles
fracture	result of cracking; parts of grains removed through conchoidal fracture; grains appear angular	surface fatigue; same as cracking
crushing	a form of fracture; breakage is not conchoidal and particles are smaller than those of fractured grains	surface fatigue; same as cracking and fracture
coarse striations	linear rows of voids; roughly parallel to grinding direction	removal of all or parts of several grains by abrasion and surface fatigue
sheen	highly reflective grain surfaces; some fractured, some unbroken; different from macroscopic sheen, which is invisible microscopically	surface fatigue and build up of tribochemical reaction products
fine striations	minute scratches across one or two flattened grain surfaces; sometimes oblique to direction of grinding	abrasion; hard wear particle or asperity scratches grain(s) on opposing surface
grain flattening	areas of smooth, planar grain surfaces; sometimes grains are level with bottoms of interstices	surface fatigue, abrasive, adhesive, and tribochemical wear; reaction products may fill some interstices
pitting	minute roughening of flattened and unflattened grain surfaces; gives the appearance of frosted glass	adhesive wear and/or chemical etching; higher magnification necessary

[1] Compare to observations in Adams (1988, 1989a, 1989b, 1992).

[2] Precise relationships between tribological mechanisms and wear traces are not understood. The relationships proposed here are based on Czichos (1978), Adams (1988, 1989a, 1989b), and on personal observations, but further research is needed.

discrepancies by comparing areas with similar amounts of wear. Topographic highs with macroscopic sheen were not compared to lows with little or no sheen. Most microwear traces are more easily distinguished at 80X than at lower magnifications. For comparative purposes, Figure 7a shows a sample of unworn stone used for the experimental tools.

Tool Set #1--Chokecherries. Grains in the high areas on the chokecherry tools are flattened to the bottoms of many of the interstices (Figure 7b). The tops of remaining voids have had tiny flakes fractured from them and are more rounded than angular. The flake scars are the only areas with sheen in flattened surfaces. The rest of the surface, even down to the bottoms of the interstices, is heavily pitted suggesting the operation of adhesive and/or tribochemical wear. Because the chokecherry meal fills the interstices and coats the surface during use, catastrophic grain failure seen as cracking, crushing, and fracture are not as prevalent. Adams (1989a:267) made a similar observation for corn meal on a mano, but with the result that only the tops of the grains were cracked; the sides were protected by corn meal filling the interstices. Two coarse striations are present on the chokecherry mano; none were observed on the metate. There are occasional fine striations. Sheen is more common in topographic lows, owing partly to the presence of more fractured grain surfaces. But there are also some unbroken grain surfaces with sheen caused by build-up of tribochemical reaction products. The latter type of sheen is what Adams (1988:308, 312) reports on hide processing stones, albeit to a much greater extent than on the chokecherry grinding tools. Pitting in topographic lows extends



a) sample of unworn stone used for experimental tools

b) chokecherry metate (#1) after 28:07 of grinding

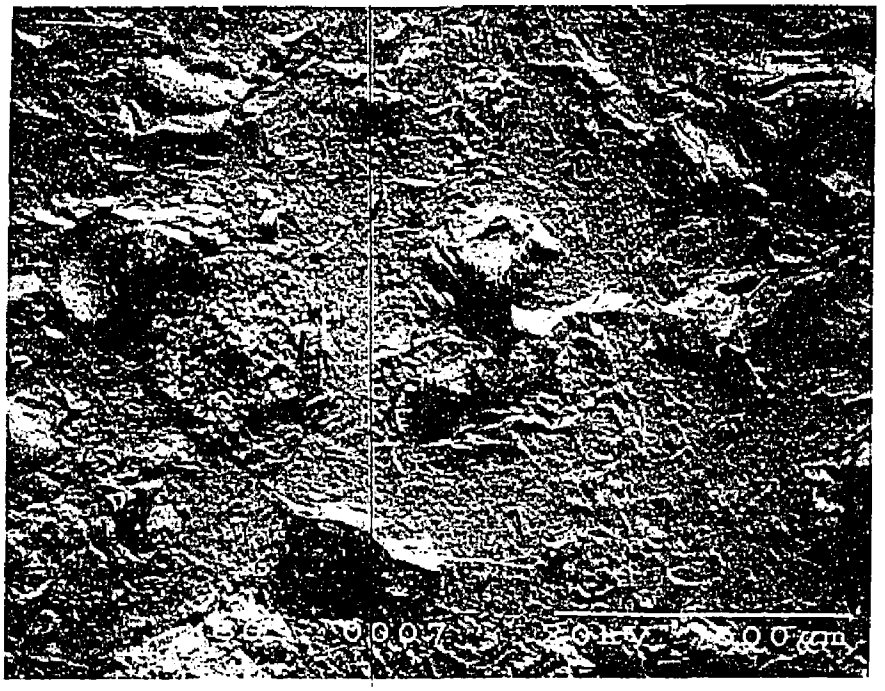
Figure 7 SEM photomicrographs (80X) of unworn stone and chokecherry metate (#1) after use

all the way down grain sides into the interstices showing that interaction between the chokecherry meal and the tool surfaces caused wear.

Tool Set #2--Wheat. The distal edge of the wheat grinding mano is similar in appearance to the most worn areas of the chokecherry tools even though it was used for eight hours less (20:08) than those tools. Wear rate and applied load are clearly associated. The distal edge of the wheat grinding mano bore a heavier load than the rest of the use face during grinding so it experiences more severe wear. Aside from the distal edge of the wheat grinding mano, the high spots on the wheat grinding tools are not quite as smooth as on the chokecherry tools (Figure 8a). This could be a function of use-time. Some grains, however, are flattened down to the bottoms of the interstices. Voids are numerous, and cracking, crushing, and fracture are still evident, especially around the tops of interstices. There is sheen on fractured surfaces and on rounded grains in the high spots. There are occasional fine striations across grain surfaces. Crude striations are absent on the metate but there are two in the proximal-right area of the mano use-face. In contrast to the chokecherry grinding tools, pitting does not extend as far down into interstices and is not so well developed. Low spots show only slight pitting, numerous instances of sheen from fractured grains and tribochemical build up, and cracking. Predictably, areas of intermediate elevation exhibit a mix of damage patterns. The tops of some grains are flattened and invariably pitted.

Tool Set #3--Crickets. After only 3 hours and 53 minutes of use, the topographic highs on the cricket grinding tools (Figure 8b) are leveled as much as those

a) wheat metate (#2) after 20:08 of grinding



b) cricket metate (#3) after 3:53 of grinding

Figure 8 SEM photomicrographs (80X) of metates #2 and #3 after use

on the wheat grinding tools. Evidence of the heavier wear mechanisms of surface fatigue and abrasion is present in the form of cracked, crushed, and fractured grains, especially around voids. Tribochemical sheen on rounded grain surfaces is far more abundant than on either the chokecherry or wheat tools. This sheen occurs on both flake sides and tops. Sheen from flake scars on fractured grains is also common. The surface appears glittery. Pitting is present on flattened grains, but is uncommon and poorly developed in interstices. There are occasional coarse and fine striations on high spots.

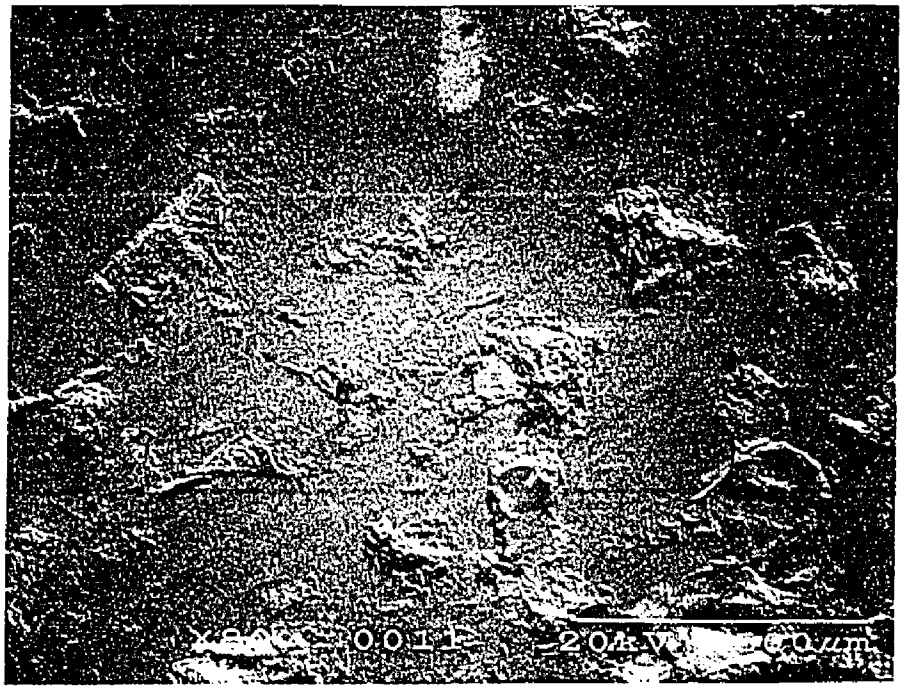
Tool Set #4--Dried Meat. Despite its considerably shorter use-time (4:26), the topographic highs on the dried meat tools look similar to those of the chokecherry tools (28:07). Pitting extends down into the bottoms of voids, though it is not as well developed. Crushing, cracking, and fracture were still occurring at the end of the use-time, but there is less evidence of this than on the wheat grinding tools. There are occasional coarse and fine striations on the metate. None were observed on the mano. Sheen is mostly limited to flake scars around the tops of interstices, but a few rounded grain surfaces within interstices have tribochemical sheen. In low spots, some grains are unworn. A good amount of microtopography remains. Cracking and fracture are noticeable but are not common. When there is sheen in topographic lows, it is not always limited to the tops of grains. There definitely appears to be tribochemical sheen on some grains in the lows.

Tool Set #5--Rock Salt. High spots on the salt grinding tools are not worn as flat as on the dried meat and chokecherry tools (Figure 9a). Although there is

considerably less microtopography than at the lower elevations, only a few interstices have been obliterated. Grain removal has left numerous voids. Some grains have been crushed but not yet removed, leaving a white powdery appearance other than that of salt residue. Interstices are angular, and cracking and fracture are common even around interstices in the flattest areas. Low magnification reveals a few coarse striations on the metate. A few fine striations are present on both salt grinding tools. Pitting extends down into voids but is not as well developed anywhere on these tools as on the chokecherry and dried meat grinding tools. Perhaps the salt does not adhere to the grain surfaces as well as moister, more pliable intermediate substances. As with the wheat grinding tools, pitting also does not extend all the way down the sides of the grains. Sheen is present both on the flake scars of fractured grains and on unbroken, round grain surfaces. Much of the sheen is interspersed with pitting on the tops of flattened grains. Cracking, crushing, and fracture are the dominant traces in topographic lows. There is very little pitting in these areas and about the same amount of sheen as in high areas.

Tool Set #6--Control. These tools are the smoothest of all the grinding tools (Figure 9b). Many interstices have been obliterated. Even though grain flattening is extreme, remaining interstices are angular, cracked, crushed, and fractured. Pitting is barely evident on flattened grain surfaces, having occurred on such a fine scale that higher magnification is necessary to see it clearly. Pitting is not visible in interstices. Fine striations also occur on an incredibly fine scale. Under 80X, they are visible only as hair-like streaks parallel with grinding direction. The fine scale

a) salt metate (#5) after 15:57 of grinding



b) control metate (#6) after 15:00 of grinding

Figure 9 SEM photomicrographs (80X) of metates #5 and #6 after use

of pitting and extreme flattening lend a translucence to the surface. Sheen is present on the slightly rounded edges of grains that have been flattened almost to the bottoms of interstices and also on fractured grains. Intermediate elevations appear very similar to the smoothest areas on the salt grinding tools. Topographic lows received little wear because of the rigid contact between the tools. There is occasional sheen, fracture, and cracking. Pitting and striations are absent.

Discussion

Although lack of control for use-time makes it difficult to isolate precisely the effects of different intermediate substances on wear variability, some general trends can be identified. These trends are similar in nature to some observed by Adams (1989b). In her discussion of various wear patterns, Adams (1989a, 1989b, 1992) distinguishes between different types of surface interactions (stone-on-stone, wood-on-stone, bone-on-stone, hide-on-stone, etc.). From this perspective, all of the grinding in the current study falls under the category of stone-on-stone contact. But as she points out, the cause of wear is not limited to actual stone-on-stone contact. Although intermediate substances reduce the amount of contact between the mano and metate faces by providing lubrication, "they also become involved in the wear process through the adhesive and tribochemical wear processes" (1989b:271-272). However, the different macro- and microwear patterns observed on the experimental tools suggest that the various substances did not act equally as lubricants or wear agents.

Chokecherries, for instance, produced extensive macrowear in topographic lows. They isolated the mano and metate from one another fairly well, minimizing the formation of macroscopic sheen from stone-on-stone contact, but there was an almost complete erasure of manufactured topography in some of the lows. The salt grinding tools (#5) suffered relatively little loss of pecking in nearly 16 hours of use; wear occurred mainly on topographic highs. The lows exhibit little to no macrowear. Clearly, salt and chokecherries act differently as lubricants. The obliteration of pecking on areas of the chokecherry tools that were not subject to stone-on-stone contact shows that the chokecherries themselves can be identified as a significant source of wear. For the salt grinding tools, the limitation of macrowear to topographic highs and the relatively lesser worn surface suggest that salt was less a source of wear than a lubricant. Wheat produced macrowear intermediate in nature to the chokecherries and salt. Some pecking was obliterated, but not as much as on the chokecherry tools. Neither crickets nor dried meat were ground long enough for reliable comparison to the other materials ground, but the fact that the distal edge of the cricket grinding mano (#3) was more rounded than the distal edge of the chokecherry mano (#1) shows that cricket paste is not as good a lubricant.

Macrowear distribution on the experimental tools can be compared with Zier's (1981) observations of variability in overall wear distribution on tool surfaces in her corn grinding experiments with different tool materials. Although some of the differences resulted from stone characteristics, others were caused by differences in surface topography and differential application of load during grinding. These last

two factors were found to be significant determinants in overall wear distribution in the present experiment as well.

Wear rate was studied on archaeological/experimental tools by Wright (1993). Although she found differences in wear rate between tool materials, it was concluded that the amount and rate of tool material attrition would be difficult if not impossible to determine on archaeological specimens. More important for this research is her observation that sharp tools wear quickly relative to tools that are in need of sharpening. This is in agreement with observations of wear rate in this experiment.

Microwear traces also illustrate that the various intermediate substances interact differently with tool surfaces. As with Adams (1989b:271) work, differences in the types of microwear traces observed on grain surfaces and the degree to which interstices experience wear are the best indicators of variability. Whereas chokecherries caused heavy pitting both on flattened surfaces and into the bottoms of interstices, wheat and salt did not pit the tools as severely and the damage only extends part way down into the interstices. The dried meat caused pitting more similar in distribution to that observed on the chokecherry tools. Crickets caused only relatively minor pitting, more along the lines of the wheat and salt tools. Again however, the considerably shorter use-times of the cricket and dried meat grinding tools make comparisons of pitting severity unreliable.

Tool sets with less severe pitting had more evidence of crushing, grain fracture, and sheen on fractured grain surfaces than the chokecherry and dried meat grinding implements. The interstices tend toward angularity and contained crushed

rock debris, much like the wear on an experimental corn grinding mano described by Adams (1989a:267). Tribochemical sheen was observed mainly on rounded grain surfaces in interstices and topographic lows, suggesting that grinding did not allow reaction product build-up on heavily worn, flattened areas. This does not preclude the operation of tribochemical processes in these same areas; it only explains the paucity of sheen on flattened grain surfaces.

The differences in wear patterns must lie in the ways in which the various intermediate substances interact with the tool surfaces. The fact that the cricket paste resulted in a wear pattern more closely related to patterns produced by salt and wheat shows that differences in the effects of intermediate substances on wear patterns cannot be reliably explained in terms of relative hardness or softness of the materials ground. Cricket paste is easily as "soft" *and* more pliable than either chokecherry meal or pounded and ground dried meat. The paste has the ability to be pushed into interstices during grinding, just as Adams (1988:312) observed for hide. Yet cricket grinding did not produce extensive wear in the interstices of the tool surfaces. This raises the question: what qualities do crickets (or any other substance) have that determines how they interact with grinding implements and cause wear. Much more work is necessary along these lines. In addition, the roles of intermediate substances as lubricants needs to be addressed in detail. The fact that the control (#6) tools lost far more mass in a shorter time than three other sets of tools (chokecherries [#1], wheat [#2], salt [#5]) shows that these intermediate substances acted as lubricants in addition to causing wear.

CONCLUSIONS

The primary goal of this experiment was to build on previous ground stone research. Some of the observations reported here support those made in earlier studies (Adams 1988, 1989a, 1989b, 1992; Wright 1993; Zier 1981). Several factors influencing wear have been identified. The control tools show that stone-on-stone contact causes the fastest wear (at least on "sharp", rough tools). Variability in wear rate deriving from the materials ground depends largely on their qualities as lubricants. Different intermediate substances do not act equally as lubricants. Similarly, qualitative differences in wear patterns attributable to materials ground are dependent on how those substances interact with the tool surfaces, an area in need of further research.

More and more evidence is coming to light supporting the notion that grinding different materials produces different wear patterns. By recognizing factors that influenced wear on the experimental tools, a deeper understanding is gained of the interpretive limits of archaeological ground stone. Factors such as use-time, rate of resharpening, natural surface topography, and material ground interact to determine wear patterns. One factor not tested here is selection of tool material, which undoubtedly has a profound effect on tool design, use-life, grinding efficiency, and wear patterns. When all these sources of wear variability are recognized, it becomes clear that the task of interpreting ground stone wear is daunting at best. But with the accumulation of empirical data through experimentation, we are slowly

acquiring the tools needed to strengthen behavioral inference based on ground stone artifacts.

The potential for experimental ground stone studies is enormous. Wear rate has been identified as an area of importance. Experimental tests of wear rate variability between different tool materials could provide evidence that is relevant to research in raw material selection and tool design. Raw materials for grinding implements were selected for qualities such as wear resistance, ease of manufacture, and ability to grind efficiently (Bostwick and Burton 1993; Fratt and Biancaniello 1993). Experimental studies could potentially illuminate what raw material qualities are desirable in milling implements. Control for use-time, a factor overlooked in this experiment, would allow assessment of how different intermediate substances affect wear rate on the same material. Experiments in grinding efficiency and tool design can provide valuable information lacking in the often vague ethnographic literature. Finally, there is no need to limit experimentation to food grinding implements. Adams (1988, 1989a, 1989b) has shown that experimentation with a wide variety of ground stone tools provides information about not only food processing, but manufacture and maintenance of bone and wooden tools, hide processing, and manufacture and maintenance of ground stone tools themselves.

Another potentially valuable source of data derived from ground stone is the analysis of residues deposited on tools during use. In addition to pollen studies, Yohe *et al.* (1991) have demonstrated that blood residue analysis can identify fauna processed on archaeological ground stone. Furthermore, Skibo (1992:40, 85-101)

outlines methods for analyzing residues on ceramics; a similar approach to ground stone artifacts is wholly appropriate.

This research is only a preliminary step toward improved understanding of ground stone use-wear. The information gained cannot yet be used to make generalizations about the relationships between ground stone use-wear and materials ground. Only tentative explanations for differences directly observed during this research can be put forward. However, it builds on the work of others and can serve as additional footing for future studies by providing information about ground stone use-wear through controlled experimentation.

APPENDIX A: PETROGRAPHIC ANALYSIS OF TWO SAMPLES OF LYONS FORMATION SANDSTONE

Sand Sample Petrographic Analysis for Pat O'Brien*

by

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I looked at both samples. They are nearly identical and clearly come from the same formation. I have produced only one description because of the extreme similarities between the samples.

These samples comprise a quartzarenite with a composition $Q_{90}F_5L_5$. In hand sample, they are pink in color overall, bedded, with fine to medium sand. Beds are <1mm to 4mm thick, pink, gray, and white in color. Boundaries between beds in sample 1 tend to be less sharply defined than those in sample 2. They are otherwise the same.

In thin section, the grains identified are as follows:

Quartz: 90% total sample, in the .125 to .4 mm range, equant to prolate, subround to very round. Pressure solution is occurring along grain boundaries. Quartz appears to have a plutonic origin.

Feldspar: 3 to 5% of total sample, alkali feldspars are most common (orthoclase, albite). Some minor oligoclase may be present. Equant to prolate, round, generally <.25mm in size.

Rock fragments 1 to 5%. Chert and volcanic felsic rock(?) are present. Rock fragments are generally round, equant, and <.2mm in length.

Labile biotite is squished around the grain boundaries of quartz and feldspar.

Iron oxides and minor rutile also occur between silicic grains.

There is bedding in this sandstone -- the beds are on the order of 1 to 4mm thick and alternate between larger (.25 to .4mm) grains of quartz with very little rock or feldspar and thinner (<=1mm) bands with 5 to 10% feldspar and around 5% rock fragments. The quartz in these thin bands tends to be <=.25mm, and the grains are more prolate and subround instead of round on the whole.

The pink color comes from the 2 to 4% iron oxides/oxidized biotite found along the grain boundaries.

Pore space in this rock is high - about 15 to 20%, and the pores are as large as the quartz grains.

* The original of this report is on file in the Laboratory of Traditional Technology, Department of Anthropology, University of Arizona, Tucson -- Patrick K. O'Brien.

APPENDIX B: METRIC ATTRIBUTES OF EXPERIMENTAL TOOLS

Tables B-1 and B-2 show the detailed metric attributes of the manos and metates. The lengths, widths, and thicknesses of the metates did not change during the experiment, so they are included only as they were measured before the experiment.

Table B-1 Experimental metate attributes

metate	length (mm)	width (mm)	thickness (mm)	pecked area length	pecked area width	mass before	mass after	%loss
1	302	202	58	235	145	8,999	8,957	0.47
2	303	202	59	235	137	8,990	8,953	0.41
3	302	197	58	227	147	9,115	9,087	0.31
4	302	203	58	240	147	9,304	9,282	0.24
5	302	200	59	245	147	9,161	9,131	0.33
6	305	202	59	235	145	9,424	9,349	0.80

Table B-2 Experimental mano attributes

mano	length before	length after	width before	width after	thickness before	thickness after	mass before	mass after	%loss
1	113	110	35	40	85	84	1,572	1,550	1.40
2	117	117	37	41	85	85	1,612	1,596	0.99
3	122	122	38	44	84	83	1,636	1,624	0.73
4	118	113	37	39	83	82	1,604	1,574	1.87
5	116	114	40	45	85	84	1,604	1,588	1.00
6	121	119	40	75	85	83	1,704	1,669	2.05

APPENDIX C: DATA ON MATERIALS GROUND

Although this study focuses on ground stone use-wear, data were also collected on grinding efficiency as reflected in the time spent to grind similar quantities of different materials and the average amount of material loss for the various intermediate substances. Table C-1 presents data on the five intermediate substances. Mass, volume, and time data for each 150 gram bag of each material are presented in Tables C-2 through C-6.

Table C-1 Input/output and time data on materials ground

material	volume(ml) before	after	diff.	% diff.	mass(g) before	after	diff.	% diff.	time (min)
chokecherries	11,065	7,915	3,150	28.5	6,793.70	5,972.35	821.35	12.1	1,687
wheat	9,975	9,960	15	0.2	8,550.06	8,139.50	410.56	4.8	1,208
crickets	12,000	7,975	4,025	33.5	3,509.10	3,393.60	115.50	3.3	233
dried meat	*3,000	5,100	+2,100	+70.0	3,004.80	2,941.90	62.90	2.1	266
salt	21,625	19,910	1,715	8.0	25,950.09	25,751.19	198.90	0.8	957
totals:	57,665	50,860	6,805	11.8	47,807.75	46,198.54	1,609.21	3.4	4,351

* Estimate based on displacement in ml of 50 g of dried meat immersed in water. Post-grinding volume was measured separately for each 150 g bag.

It is clear that huge differences exist in the amount of work and time required to grind similar amounts of different substances. Whereas the average time spent grinding 150 g of dried chokecherries was approximately 37 minutes, it only took about five and a half minutes to grind the same amount of salt. Wheat, dried meat, and crickets took an average of 21 minutes, 13 minutes, and 10 minutes to grind per 150 g bag, respectively.

The implications for subsistence strategies are clear. Prehistoric peoples would have had to weigh the nutritional benefits of each resource against the time and energy expended in procuring and processing them. Chokecherries took by far the longest to process, but a large amount can be picked in a relatively short time. For this experiment, approximately four gallons of chokecherries were picked by two people in three and a half hours (seven person hours). Conversely (if wheat is any indication), wild grass seeds would have been more efficient to grind. But an informal experimental harvest of Indian ricegrass performed by the author and three other archaeologists yielded only about 400 g of unwinnowed, unprocessed seed in approximately three person hours of collecting. When one considers the additional factors of relative nutritional benefits and scheduling of subsistence related activities, a complex picture emerges.

One of the most interesting aspects of performing this experiment was the number of insights and ideas that arose from the food processing task. There are seemingly endless avenues of future research in the study of how ground stone technology relates to other aspects of subsistence strategy, and it is hoped that presentation of the current data will help encourage others to undertake such research.

Table C-2 Input/output and time data for chokecherries

bag #	------volume(ml)------			----------mass(g)----------			time
	before	after	diff.	before	after	diff.	(min)
1	250	150	100	150.03	110.37	39.66	58
2	250	160	90	149.99	116.72	33.27	45
3	250	175	75	150.04	132.61	17.43	46
4	250	175	75	149.95	127.42	22.53	46
5	250	175	75	150.11	133.93	16.18	46
6	250	175	75	150.04	132.00	18.04	41
7	250	175	75	150.01	133.75	16.26	40
8	250	175	75	150.05	132.17	17.88	33
9	250	175	75	149.92	127.04	22.88	35
10	250	175	75	150.07	137.05	13.02	37
11	250	175	75	150.02	135.59	14.43	35
12	250	175	75	150.01	133.04	16.97	36
13	250	175	75	150.04	131.81	18.23	36
14	250	175	75	149.96	133.60	16.36	36
15	250	175	75	150.08	133.96	16.12	37
16	250	175	75	149.98	132.83	17.15	39
17	250	175	75	150.06	134.58	15.48	35
18	250	175	75	150.02	132.09	17.93	35
19	250	175	75	149.95	133.70	16.25	38
20	250	175	75	150.01	134.33	15.68	35
21	250	175	75	150.02	134.62	15.40	33
22	250	175	75	149.98	132.20	17.78	38
23	250	175	75	150.08	133.53	16.55	38
24	250	175	75	149.99	131.41	18.58	39
25	225	160	65	150.03	131.81	18.22	38
26	225	160	65	149.95	132.56	17.39	37
27	225	160	65	150.04	131.88	18.16	32
28	225	160	65	149.98	131.58	18.40	35
29	225	160	65	149.95	128.35	21.60	33
30	225	160	65	150.02	131.07	18.95	35
31	225	160	65	150.05	133.91	16.14	33
32	225	160	65	149.97	132.78	17.19	36
33	225	160	65	150.02	130.28	19.74	34
34	225	160	65	150.05	130.77	19.28	38
35	250	180	70	149.99	128.21	21.78	33
36	250	195	55	150.13	133.10	17.03	33
37	250	190	60	150.06	133.12	16.94	35
38	250	175	75	150.02	120.78	29.24	35
39	250	190	60	150.02	127.70	22.32	30
40	250	200	50	149.93	136.46	13.47	41

Table C-2-*Continued*

bag #	------volume(ml)------			----------mass(g)----------			time
	before	after	diff.	before	after	diff.	(min)
41	250	195	55	150.05	137.41	12.64	36
42	250	195	55	150.08	137.42	12.66	36
43	250	200	50	150.00	140.04	9.96	36
44	250	200	50	150.00	137.57	12.43	33
45	250	190	60	149.97	137.46	12.51	38
46	65	45	20	42.98	37.74	5.24	13
totals:	11,065	7,915	3,150	6,793.70	5,972.35	821.35	1,687

Table C-3 Input/output and time data for wheat

bag #	------volume(ml)------			----------mass(g)----------			time
	before	after	diff.	before	after	diff.	(min)
1	175	175	0	150.02	146.43	3.59	26
2	175	185	+10	150.00	146.00	4.00	25
3	175	175	0	150.03	143.85	6.18	25
4	175	180	+ 5	150.00	145.42	4.58	27
5	175	185	+10	150.01	146.77	3.24	22
6	175	175	0	150.00	144.54	5.46	22
7	175	185	+10	149.99	144.95	5.04	22
8	175	180	+ 5	150.00	145.53	4.47	21
9	175	180	+ 5	150.00	144.33	5.67	21
10	175	180	+ 5	150.01	143.68	6.33	19
11	175	175	0	150.02	141.02	9.00	17
12	175	180	+ 5	150.01	142.10	7.91	17
13	175	175	0	150.02	142.17	7.85	17
14	175	175	0	150.00	145.35	4.65	17
15	175	175	0	149.99	140.33	9.66	16
16	175	175	0	150.01	137.50	12.51	15
17	175	175	0	150.00	131.68	18.32	17
18	175	175	0	149.99	144.28	5.71	19
19	175	175	0	150.00	143.11	6.89	18
20	175	175	0	150.00	142.77	7.23	18
21	175	175	0	150.01	140.95	9.06	15
22	175	175	0	149.99	138.98	11.01	17
23	175	155	20	150.00	132.46	17.54	18
24	175	155	20	149.99	134.94	15.05	19
25	175	175	0	150.00	144.00	6.00	20
26	175	175	0	150.00	144.38	5.62	19
27	175	175	0	149.99	143.23	6.76	18
28	175	160	15	150.00	126.81	23.19	18
29	175	175	0	150.01	141.78	8.23	19
30	175	170	5	150.01	140.56	9.45	18
31	175	175	0	150.01	144.49	5.52	23
32	175	175	0	150.01	145.18	4.83	22
33	175	175	0	150.00	146.15	3.85	20
34	175	175	0	149.99	144.62	5.37	22
35	175	175	0	150.00	144.50	5.50	22
36	175	170	5	150.01	142.60	7.41	23
37	175	175	0	150.00	144.74	5.26	21
38	175	170	5	149.99	141.34	8.65	24
39	175	175	0	150.00	143.04	6.96	23
40	175	175	0	150.02	141.57	8.45	23

Table C-3-*Continued*

bag #	------volume(ml)------			----------mass(g)----------			time
	before	after	diff.	before	after	diff.	(min)
41	175	175	0	150.00	142.95	7.05	25
42	175	175	0	149.98	145.23	4.75	23
43	175	175	0	150.00	144.04	5.96	22
44	175	175	0	150.00	143.26	6.74	22
45	175	175	0	150.00	141.54	8.46	20
46	175	175	0	149.99	142.58	7.41	20
47	175	175	0	150.00	143.30	6.70	24
48	175	175	0	150.01	144.51	5.50	24
49	175	175	0	150.00	144.53	5.47	22
50	175	175	0	149.98	142.66	7.32	25
51	175	175	0	150.02	147.06	2.96	27
52	175	175	0	149.99	146.10	3.89	24
53	175	175	0	150.00	145.59	4.41	26
54	175	175	0	149.99	145.54	4.45	25
55	175	175	0	149.98	144.67	5.31	25
56	175	175	0	150.00	144.10	5.90	24
57	175	175	0	149.99	143.71	6.28	25
totals:	9,975	9,960	15	8,550.06	8,139.5	410.56	1,208

Table C-4 Input/output and time data for crickets

bag #	------volume(ml)------			----------mass(g)----------			time
	before	after	diff.	before	after	diff.	(min)
1	950	375	575	148.0	147.4	0.60	12
2	500	350	150	149.9	138.5	11.40	15
3	500	300	200	150.2	148.4	1.80	10
4	500	350	150	150.4	152.8	+2.40	12
5	500	350	150	150.3	149.9	0.40	10
6	500	350	150	150.0	147.4	2.60	8
7	500	350	150	150.7	147.7	3.00	9
8	500	350	150	149.9	151.7	+1.80	10
9	500	350	150	150.1	142.3	7.80	10
10	500	350	150	150.1	152.5	+2.40	12
11	500	300	200	150.1	137.8	12.30	11
12	500	300	200	150.0	142.9	7.10	8
13	500	350	150	150.1	142.6	7.50	9
14	500	350	150	150.0	142.3	7.70	9
15	500	350	150	150.4	142.6	7.80	9
16	500	300	200	150.1	143.4	6.70	9
17	500	350	150	150.3	143.7	6.60	9
18	500	350	150	150.0	146.3	3.70	9
19	500	350	150	150.0	144.0	6.00	9
20	500	350	150	149.8	143.7	6.10	9
21	500	350	150	150.1	144.4	5.70	9
22	500	300	200	149.9	140.3	9.60	10
23	500	350	150	150.4	142.6	7.80	10
24	500	150	350	58.3	58.4	+0.10	5
totals:	12,000	7,975	4,025	3,509.1	3,393.6	115.5	233

Table C-5 Input/output and time data for dried meat

bag #	------volume(ml)------			----------mass(g)----------			time
	before	after	diff.	before	after	diff.	(min)
1	150	300	+150	150.6	143.4	7.2	12
2	150	300	+150	150.1	146.2	3.9	14
3	150	250	+100	150.3	140.7	9.6	10
4	150	250	+100	150.1	150.7	+0.6	12
5	150	200	+50	150.0	144.7	5.3	13
6	150	200	+50	150.1	146.7	3.4	13
7	150	250	+100	150.3	147.6	2.7	10
8	150	250	+100	150.3	148.1	2.2	18
9	150	300	+150	150.3	151.8	+1.5	19
10	150	250	+100	150.0	145.6	4.4	13
11	150	250	+100	150.7	148.8	1.9	10
12	150	250	+100	150.0	148.0	2.0	12
13	150	250	+100	150.0	146.3	3.7	13
14	150	300	+150	150.2	147.0	3.2	13
15	150	250	+100	150.4	149.2	1.2	12
16	150	250	+100	150.0	148.6	1.4	16
17	150	250	+100	150.5	148.6	1.9	13
18	150	250	+100	150.4	146.7	3.7	16
19	150	250	+100	150.5	146.3	4.2	14
20	150	250	+100	150.0	146.9	3.1	13
totals:	3,000	5,100	+2,100	3,004.8	2,941.9	62.9	266

Table C-6 Input/output and time data for rock salt

bag #	------volume(ml)------			----------mass(g)----------			time
	before	after	diff.	before	after	diff.	(min)
1	125	115	10	149.99	145.66	4.33	7
2	125	115	10	150.01	149.39	0.62	7
3	125	115	10	150.00	149.49	0.51	6
4	125	120	5	150.01	147.91	2.10	6
5	125	120	5	149.99	148.70	1.29	6
6	125	125	0	150.02	148.59	1.43	6
7	125	120	5	150.00	148.36	1.64	6
8	125	115	10	150.02	149.08	0.94	4
9	125	115	10	150.00	148.56	1.44	5
10	125	115	10	150.00	149.53	0.47	5
11	125	115	10	150.00	149.51	0.49	5
12	125	115	10	150.02	149.33	0.69	6
13	125	120	5	150.00	149.29	0.71	5
14	125	115	10	150.01	148.67	1.34	5
15	125	115	10	150.02	148.46	1.56	5
16	125	115	10	150.03	149.61	0.42	5
17	125	115	10	150.00	149.19	0.81	6
18	125	115	10	150.00	146.61	3.39	5
19	125	115	10	150.00	148.01	1.99	5
20	125	115	10	150.00	148.89	1.11	5
21	125	115	10	150.00	149.01	0.99	5
22	125	115	10	150.02	148.56	1.46	5
23	125	115	10	150.01	148.32	1.69	5
24	125	115	10	150.00	148.35	1.65	5
25	125	115	10	150.00	148.72	1.28	6
26	125	115	10	150.00	148.30	1.70	5
27	125	115	10	150.00	147.67	2.33	5
28	125	115	10	150.00	148.40	1.60	6
29	125	115	10	150.00	148.50	1.50	5
30	125	110	15	150.01	147.25	2.76	5
31	125	110	15	150.00	143.40	6.60	5
32	125	115	10	150.01	148.82	1.19	5
33	125	115	10	149.99	147.60	2.39	6
34	125	115	10	150.00	148.68	1.32	5
35	125	115	10	149.99	148.26	1.73	6
36	125	115	10	150.00	149.01	0.99	5
37	125	115	10	149.99	149.26	0.73	6
38	125	115	10	150.00	148.77	1.23	6
39	125	115	10	150.01	149.12	0.89	5
40	125	115	10	149.99	148.56	1.43	5

Table C-6-*Continued*

bag #	------volume(ml)------			----------mass(g)----------			time
	before	after	diff.	before	after	diff.	(min)
41	125	110	15	150.00	148.90	1.10	5
42	125	115	10	149.99	148.60	1.39	5
43	125	115	10	150.01	148.69	1.32	5
44	125	115	10	150.00	149.18	0.82	5
45	125	115	10	150.00	148.48	1.52	5
46	125	115	10	150.01	148.67	1.34	5
47	125	115	10	149.99	149.11	0.88	5
48	125	115	10	150.00	149.22	0.78	6
49	125	115	10	150.00	148.47	1.53	6
50	125	115	10	149.99	148.87	1.12	6
51	125	115	10	150.00	148.98	1.02	6
52	125	115	10	149.99	148.95	1.04	5
53	125	115	10	150.00	149.10	0.90	6
54	125	115	10	149.99	148.89	1.10	6
55	125	115	10	149.99	148.60	1.39	5
56	125	115	10	150.00	148.47	1.53	6
57	125	115	10	150.00	148.82	1.18	6
58	125	115	10	150.01	149.06	0.95	5
59	125	115	10	149.99	148.82	1.17	6
60	125	115	10	150.00	148.67	1.33	5
61	125	115	10	150.01	148.68	1.33	5
62	125	115	10	150.00	149.23	0.77	5
63	125	115	10	150.01	148.63	1.38	5
64	125	115	10	150.01	149.09	0.92	5
65	125	115	10	150.00	148.91	1.09	5
66	125	115	10	149.99	149.36	0.63	5
67	125	115	10	150.01	148.90	1.11	5
68	125	115	10	150.00	148.23	1.77	6
69	125	115	10	150.00	149.27	0.73	5
70	125	115	10	150.01	148.96	1.05	5
71	125	115	10	150.00	148.76	1.24	6
72	125	115	10	149.99	149.96	0.03	6
73	125	115	10	149.99	148.78	1.21	6
74	125	115	10	150.00	148.81	1.19	5
75	125	115	10	150.00	148.96	1.04	6
76	125	115	10	150.01	149.03	0.98	6
77	125	115	10	149.99	149.06	0.93	5
78	125	115	10	150.00	149.03	0.97	5
79	125	115	10	150.01	148.96	1.05	5
80	125	115	10	149.99	148.67	1.32	6

Table C-6-*Continued*

bag #	------volume(ml)------			----------mass(g)----------			time
	before	after	diff.	before	after	diff.	(min)
81	125	115	10	150.00	148.60	1.40	6
82	125	115	10	149.99	148.68	1.31	5
83	125	115	10	150.01	148.63	1.38	5
84	125	115	10	150.01	148.82	1.19	5
85	125	115	10	150.00	148.57	1.43	5
86	125	115	10	150.01	149.19	0.82	6
87	125	115	10	149.99	148.67	1.32	6
88	125	115	10	150.00	148.97	1.03	5
89	125	115	10	149.99	147.81	2.18	5
90	125	115	10	150.00	148.83	1.17	6
91	125	115	10	149.99	148.50	1.49	6
92	125	115	10	150.01	148.52	1.49	6
93	125	115	10	149.99	149.37	0.62	6
94	125	115	10	150.00	148.72	1.28	6
95	125	115	10	150.00	149.29	0.71	5
96	125	115	10	150.00	148.70	1.30	6
97	125	115	10	150.00	149.12	0.88	6
98	125	115	10	149.99	148.89	1.10	5
99	125	115	10	149.99	149.00	0.99	5
100	125	115	10	150.00	149.06	0.94	6
101	125	115	10	150.01	148.79	1.22	6
102	125	115	10	150.00	149.19	0.81	6
103	125	115	10	150.01	149.13	0.88	6
104	125	115	10	150.00	149.22	0.78	5
105	125	115	10	149.99	149.01	0.98	5
106	125	115	10	150.01	148.74	1.27	6
107	125	115	10	149.99	149.03	0.96	5
108	125	115	10	150.02	148.97	1.05	5
109	125	115	10	149.99	149.08	0.91	5
110	125	115	10	150.01	149.06	0.95	5
111	125	115	10	150.00	148.48	1.52	5
112	125	115	10	150.00	149.03	0.97	5
113	125	115	10	150.00	148.58	1.42	6
114	125	115	10	150.00	149.03	0.97	5
115	125	115	10	149.99	148.97	1.02	5
116	125	115	10	150.00	148.79	1.21	5
117	125	115	10	150.01	148.76	1.25	6
118	125	115	10	150.01	148.96	1.05	6
119	125	115	10	150.01	148.48	1.53	5
120	125	115	10	149.99	148.87	1.12	5

Table C-6-*Continued*

bag #	------volume(ml)------			----------mass(g)----------			time
	before	after	diff.	before	after	diff.	(min)
121	125	115	10	150.00	148.87	1.13	6
122	125	115	10	149.99	148.97	1.02	7
123	125	115	10	150.00	149.08	0.92	6
124	125	115	10	150.00	149.43	0.57	6
125	125	115	10	150.00	149.23	0.77	6
126	125	115	10	150.01	149.27	0.74	6
127	125	115	10	150.00	149.11	0.89	6
128	125	115	10	150.00	149.01	0.99	6
129	125	115	10	149.99	149.16	0.83	5
130	125	115	10	150.00	149.24	0.76	5
131	125	115	10	149.99	148.94	1.05	5
132	125	115	10	149.99	149.10	0.89	5
133	125	115	10	150.01	148.90	1.11	6
134	125	115	10	149.99	149.27	0.72	6
135	125	115	10	150.00	149.20	0.80	6
136	125	115	10	149.99	149.27	0.72	5
137	125	115	10	150.00	149.00	1.00	6
138	125	115	10	150.00	149.35	0.65	5
139	125	115	10	150.00	149.18	0.82	6
140	125	115	10	149.99	149.50	0.49	6
141	125	115	10	150.00	149.19	0.81	5
142	125	115	10	150.01	149.17	0.84	6
143	125	115	10	150.00	149.20	0.80	6
144	125	115	10	149.99	149.15	0.84	6
145	125	115	10	149.99	148.88	1.11	5
146	125	115	10	150.00	149.23	0.77	5
147	125	115	10	150.01	148.68	1.33	6
148	125	115	10	150.01	149.06	0.95	4
149	125	115	10	150.00	148.91	1.09	6
150	125	115	10	150.00	149.15	0.85	5
151	125	115	10	150.00	149.41	0.59	6
152	125	115	10	150.01	149.37	0.64	6
153	125	115	10	150.00	149.39	0.61	6
154	125	115	10	150.00	149.35	0.65	6
155	125	115	10	150.00	149.27	0.73	6
156	125	115	10	150.01	149.17	0.84	6
157	125	115	10	150.00	149.18	0.82	5
158	125	115	10	150.00	149.28	0.72	6
159	125	115	10	150.00	149.36	0.64	6
160	125	115	10	150.00	148.98	1.02	6

Table C-6-*Continued*

bag #	------volume(ml)------			----------mass(g)----------			time
	before	after	diff.	before	after	diff.	(min)
161	125	115	10	149.99	148.45	1.54	6
162	125	115	10	149.99	148.96	1.03	7
163	125	115	10	150.00	149.57	0.43	6
164	125	115	10	150.01	149.28	0.73	6
165	125	115	10	150.00	149.39	0.61	6
166	125	115	10	150.00	149.07	0.93	6
167	125	115	10	150.00	149.36	0.64	6
168	125	115	10	149.99	148.76	1.23	6
169	125	115	10	150.00	148.47	1.53	6
170	125	115	10	150.00	148.95	1.05	6
171	125	115	10	150.01	149.07	0.94	6
172	125	115	10	150.00	148.71	1.29	6
173	125	115	10	149.99	149.35	0.64	6
totals:	21,625	19,910	1,715	25,950.09	25,751.19	198.90	957

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