Lithic Raw Material Variability and the Reduction of Short-term Use Implements: An Example from Northwestern New Mexico.

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ABSTRACT

Chipped stone tools are a truly dynamic medium of material culture. From initial reduction to contemporary excavation, lithic artifacts undergo continuous change. The role of the properties of raw materials in determining rates of use-wear accrual is poorly understood and has rarely been assessed quantitatively (e.g. Goodman, 1944; Greiser and Sheets, 1979; McDevitt, 1994). This dissertation offers such quantification regarding four materials exploited for the production of short-term use implements at the Late Archaic FA2-13 site located just outside the city of Farmington, New Mexico.

Both experimental and archaeological use-wear evidence was assessed in separate but related ways. Digital image analysis of use-wear invasiveness using ClemexVision PE and GIS analysis of use-wear homogeneity using Idrisi Kilimanjaro yielded distinct but highly complementary results. Direct testing of material properties of non-archaeological samples using a Hysitron Triboindenter served to further clarify these findings in terms of the complex relationship between raw material surface hardness and roughness.

The results of the present study show that there are significant differences between rates of wear accrual among the four materials. Analysis of tools from FA2-13 indicates that while scraping activities likely did predominate (Schutt, 1997a), it may also be feasible to generate more detailed assessments regarding the kinds of scraping activities that were undertaken and the respective intensities with which they were performed. This increased insight can then be extrapolated for application to long-term use technologies and their more complex life histories.

RÉSUMÉ

Les outils en pierre taillée représentent un moyen dynamique pour l'étude de la culture matérielle. Depuis leur fabrication initiale jusqu'au moment de leur récupération parvoie de l'archéologie les artifacts lithiques subissent une modification continuelle. Le rôle des caractères eristiques particulièrres de la source de matière première qui déterminent le taux d'usure est mal compris et ceci a été infréquemment évalué sur le plan quantitatif (e.g. Goodman.1994, Greiser and Sheets, 1979; McDevitt, 1994). Cette thèse propose une telle quantification basée sur un examen de quatre ressources exploitées pour la fabrication des outils destines à une utilisation à court terme surle site FA2-13 datant de la période de l'Archäique Supérieur aux alentours de la ville de Farmington dans l'état de New Mexico.

L'évidence d'usure de provenance archéologique ainsi qu'expérimenale fut évaluée de deux perspectives distinctes mais en même temps reliées. L'analyse des images numériques de l'usure invahissante par moyen du logiciel Clemex Vision PE et l'analyse GIS de l'homogénéité de l'usure par le logiciel Idrisi Kilimanjaro ont rendu des resultats bien distincts mais complémentaires. Un sondage des caractères des ressources non-archéologiques par moyen d'un Hysitron Triboindenter a servi à éclaircir ces conclusions et à confirmer la relation complexe qui existe entre la dureté de la superficie et la rugosité de la matière première.

Cette étude démontre aussi qu'il y a des différences significatives entre le taux d'usure parmi les quatre matières. L'analyse des outils du site FA2-13 où les racloirs et les grattoirs semblent prédominer (Schutt,1997a) suggère qu'il serait envisagable de faire un sondage plus profond et plus détaillé sur le type et l'intensité des activités de

raclage. Cet aperçu augmenté pourrait s'appliquer à l'étude de la technologie de la fabrication des outils à usage long terme et à l'histoire de leur persistence.

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Although I am listed as the sole author of this thesis it was truly the product of many peoples' help and support. Without all of their time and effort this study would undoubtedly have proven a far more arduous a task to complete. The success of this thesis is due in no small part to these people and the wealth of knowledge and experience they collectively possess.

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As with any program of research, this thesis would not have been possible without the several sources of financial support I received during my doctoral studies. The Samuel Lapitsky Fellowship and two McGill Graduate Studies Fellowships helped to fund fieldwork and laboratory analysis. The work with the Hysitron Triboindenter was made possible through NSERC and the Canadian Research Chairs Program, and McGill University and their internal SSHRC funding program provided funds for the SEM work and covered the costs of geological sample preparation.

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CHAPTER 1: INTRODUCTION

This study tackles issues both large and small. Given the realities of academic research, some of them are dealt with in greater detail than others, but the fact that all of these issues are inextricably linked with one another informed every stage of this research. The fundamental questions being asked here are:

1) How does the role of raw material in use-wear formation affect assessment of use intensity?
2) What insights might we gain from such research regarding the respective roles of different activities in larger subsistence strategies?
3) What implications does such research have for future studies dealing with the effects of raw material type on chipped stone tool life histories, and for lithic analysis in general?

While the considerable breadth of these questions precludes their thorough and complete explication, this dissertation will explore a number of issues key to their resolution. Before delving into any of them, some background on this study's evolution will serve as a useful introduction.

Conceptual Underpinnings of Conventional Lithic Research

For most of this discipline's intellectual history efforts to recover cultural meaning have resulted in both methodological refinement and epistemological stagnation. Time-honoured typological traditions (e.g. Kidder, 1932; MacNeish, 1952; McKern, 1939; Phagan, 1988a/b; Ritchie, 1961) have guided our collective pursuit of the prehistoric past by structuring our quest for such knowledge to the point of significantly limiting our results. The ordering of a lithic assemblage into a series of morpho-functional types has the effect of imposing certain cultural meanings onto these materials while interpretively closing the door on others. If a given outline morphology is recognized as being associated with the scraping of animal hides, such as a tear-drop shaped end-scraper, then once it is documented for a particular implement, it is often assumed that the tool spent the majority of its functional life history serving that purpose (Honea, 1965b). Surprisingly little thought is subsequently given to how this artifact ultimately reached this technical state of affairs. Classificatory systems offer a sense of order in the face of artifactual chaos, but they also structure our inferences about the past. Thus it is ironic that the construction of typologies should have shared so much intellectual history with as dynamic a medium as lithic technology.

Perhaps the most obvious shared trait in this dichotomy is their reductive natures. Lithic technology is based upon the reduction of raw material to produce useable tools. The result of this process is a continuous decrease in size of the parent stone and loss of material volume. Typologies also involve an element of loss, but one of inferential rather than physical substance. The conceptual compartmentalization of material culture, while providing a means of placing individual occupations within established culture-chronological frameworks, reduces the population involved to little more than a collection of cultural elements. Often lacking in archaeological research today is a form of cultural refitting to re-integrate these typologically separated elements (cf. O'Brien and Lyman, 2003). Much like the debitage used in reconstructing the reduction sequence of a single flint nodule, typological categories are the classificatory debitage of a once much larger cultural whole.

In even a partial reconstruction of past social dynamics we need to recognize not only the various components of prehistoric society but also the relations that bound them together culturally. This applies as equally to settlement patterns, subsistence strategies, and group cosmologies, as it does to all components of material culture. Lithic technology is no exception; in fact this portion of the archaeological record, with its vast temporal and spatial scope, represents a rather acute example of interpretive fragmentation and taxonomic reduction.

Projectile points, for example, have been the focus of an extensive amount research over the years, yet their interpretation has long been guided by the same set of limited research questions (e.g. Bodner *et. al.*, n.d.; Phagan, 1988a/b; Ritchie, 1961). These include what such implements can tell us regarding the animal resources they were used to exploit, what the raw materials used in their production can tell us about how they moved across the prehistoric landscape and most often what they suggest about the age of the site from which they derive. Several advances have been made in refining our methods for identifying and using distinct point types as legitimate cultural markers, but the goal of typological ordering has remained essentially the same over time. Projectiles have long been subjected to morphological classification as a corroborative element in constructing culture histories.

A by-product of this methodological tradition is that different point types continue to be seen as mutually distinct cultural elements. The possibility that on a given site several point types may represent various stages of a shared reduction trajectory or life history rather than a series of deliberately sought after end products is frequently overlooked. As a result, the relationships between different projectile forms within a given assemblage have, with few exceptions (e.g. Flenniken, 1985), received little analytical attention. This has limited our ability to make inferences about the people and behaviours responsible for producing these implements.

An understanding of how different tool forms, and the stages of their life histories they represent relate to one another is critical in any effort to reveal dynamic processes from a static archaeological record. Although we can never get inside the mind of a prehistoric craftsman, it is still possible to piece together some of the decisions he or she made based on the inter-relatedness of the surviving physical evidence. From this perspective, a wide array of research issues can be revisited in a more comprehensive and dynamic way.

Beyond the reductive nature of traditional typologies, the scope of reduction as an analytical concept also needs to be addressed. Unlike the *Chaine Operatoire* of European lithic research, analyses of reduction sequences in the western world have tended to delve into the choices knappers made during initial flake blank generation and the shaping of initial tool forms. Tool modification, however, does not end once a given implement reaches the final stage of production. It continues unabated well beyond final deposition into the archaeological record. Intensity and variability of use, maintenance and recycling, and post-depositional processes all affect tool form. Given this reality, they must all be incorporated into any examination of tool life histories. It is these histories that will enlighten us as anthropologists about both the artifacts and the people that made them.

Several other analytical constructs can and should be subject to similar re-assessment, including the dichotomy between formal and expedient technologies, the nature and context of wear accrual, the problem of equifinality, the relationship between static remains and dynamic processes, the factors involved in raw material acquisition, and the role of experiments in lithic archaeology, to name but a few. Although these issues will all be touched upon in this dissertation, raw material acquisition and lithic experimentation will be emphasized, given their centrality to the research described in the following chapters.

Background and Organization of the Present Study

When I began his Masters degree the focus of this research was very different from what it would eventually become. I set out to examine the spatial distribution of various lithic tool types and attributes across a late 15th to early 16th century AD Huron village, the Keffer site, excavated near Toronto, Ontario. While initially interested in searching for any spatial patterning of tool production, use, maintenance and discard, it became clear that the more than two-hectare area of the site, the thousands of specimens in the assemblage, and the wide array of variables worth examining made this too complex an investigation for a Masters-level project.

In confronting this challenge two related issues began to emerge. During the process of selecting attributes for analysis, it was found that in the past there was a recurring tendency among researchers to recognize typological distinctions based on a limited number of morphological attributes (e.g. Ammerman and Feldman, 1974; Bell and Hall, 1953; Bodner, Weisman and Dixon, n.d.; Channen and Clarke, 1965; Poulton, 1985; Ramsden, 1990; Ritchie, 1961; White, Binford and Papworth, 1963). It seemed that many tool 'types' had been established on less then convincing conceptual grounds. Thus, the typological legitimacy of accepted tool categories needed to be established prior to any assessment of distribution patterns; otherwise it would be exceedingly difficult to determine what was clustering or why it occurred.

The second issue proved to be even more fundamental than the first. In order to determine typological legitimacy, at least on technological grounds, a re-evaluation of basic perceptions of lithic technology was necessary. This prompted some thought on the nature of tool life histories and their role in traditional lithic analyses. A thorough examination of the archaeological literature from Ontario has shown that this level of analysis has been the exception rather than the rule (e.g. Channen and Clark, 1965; Fox, 1979a; Poulton, 1985; Ramsden, 1990). This is partly a result of prevailing research interests, but also reflects a relatively limited appreciation of what lithics can tell us about their makers and their motivations.

As the implications of these two issues grew more apparent, they became the focus of my Masters research. Rather than look at how different tool types and attributes were distributed across the Keffer site, I turned my attention towards gaining a better understanding of how we as archaeologists tend to perceive lithic technology and how these perceptions influence our analytical results. I decided to pursue this by adopting a fundamentally dynamic perspective of lithic technology in lieu of the far more static assumptions associated with many traditional studies.

Hypothesizing that stone tools almost certainly changed in form and often in function in response to their manner of use, I set out to select variables for analysis that were likely most sensitive to such changes. Along with maximum dimensions and outline geometry, additional attributes needed to be considered for their ability to reflect life history stage at final discard, as well as how a given tool might relate to other specimens of the same technological type or those of similar types. A broader survey of current literature on attribute analysis and typological theory revealed certain trends among traditional assessments of lithic technology (Adams and Adams, 1991; Bonnichsen, 1977; Dunnell, 1971b; Jelinek, 1976; Krieger, 1944; McKern, 1939; Parry, 1994; Shott, 1989; Wilmsen, 1970). Expanding my review of previous research to encompass much of the North American continent resulted in the unearthing of a number of studies that greatly influenced my own.

These analyses first began to appear with greater frequency in the early 1970s, but the underlying ideas can be traced back to the late 19th century. In 1894a W. H. Holmes wrote about the natural history of stone tools from raw material acquisition to final discard. While it was generally recognized that chipped stone tools did indeed change in form over their 'lifespan', this fact would not become a significant interpretive element in lithic analysis for another seventy-five years. It wasn't until the early 1970s that the dynamic nature of stone tools re-emerged as part of their interpretation.

Albert C. Goodyear (1974) examined the lithic assemblage from the Dalton site, the type-site for Late Paleo-Indian Dalton phase in Arkansas. His assessment of the projectile points from this site took into account that they would likely have changed physically over the course of their life histories, raising the possibility that different point forms may be indicative of different developmental stages rather than distinct functional categories. Goodyear recognized five such stages ranging from preform through to functional exhaustion. While representing a fairly arbitrary breakdown of a single reduction sequence, Goodyear's stages are indicative of the inherent variability of lithic implements over the course of their life histories. Michael Schiffer formalized the ideas put forth by Holmes and applied by Goodyear in his book *Behavioral Archaeology* (1976). He distinguished between cultural and natural transformations as mechanisms for physical change in material culture. These changes are the recorded components of past processes, thus are critical for any understanding of past lifeways. Although Schiffer offered a promising framework for evaluating artifacts in more culturally dynamic terms, it has assumed only a limited role in standard lithic analysis.

C. Marshall Hoffman (1985) took a more quantitative approach to interpreting the kind of transformations Schiffer described. He examined the relationship between pairs of scalar variables as a way of gauging degree of maintenance related reduction among projectile points from the southeastern United States. Through factor analysis and canonical correlations, Hoffman demonstrated the validity of what he termed the *Blade Width/Blade Edge Angle Hypothesis*. The initial assumption he made was that as a projectile point is used and repaired the maximum width of the blade will decrease and the lateral edge angles will increase. By extension, reduction intensity due to maintenance can then be estimated based on the relative values of these variables.

This pairing of what are initially hypothesized to be related variables and the subsequent statistical testing of their relationship served as a methodological template for my Masters thesis. I not only examined the relationship between blade or midpoint width and lateral edge angle on prehistoric Huron projectile points, but also the relationships between midpoint and basal widths and overall length and tip angle in plan view. I also assessed analogous variable pairings for other traditional tool categories. For endscrapers I looked at the relationship between two angles measured at different points along the exterior surface of bit elements parallel to the long axis of each implement to determine if there is any correlation between the ratio of these angles and the extent of maintenance-related retouch. I also incorporated use-wear data I collected in an earlier study (Lerner n.d.) in an attempt to recognize the different use-related stages of these endscrapers' life histories.

While I was able to identify certain patterns in tool form that appear to correspond to different life history stages within common reduction trajectories, there were still a number of variables unaccounted for. One factor that remained essentially unexamined is the effect of lithic raw material type on tool production, use and maintenance. Over eighty-five percent of the Keffer lithic assemblage was produced on Onondaga chert, thus rendering any assessment of raw material variability as a factor in reduction intensity impractical.

The necessity of finding an assemblage comprised of a variety of raw material types and a longstanding interest in the area's prehistory resulted in the redirection of analytical attention from southern Ontario to northwestern New Mexico. The site I ultimately settled on, FA2-13 (LA 33741), is located in the San Juan Basin, near the modern city of Farmington, in northwestern New Mexico. It was occupied repeatedly from 1800 BC to AD 200 and yielded a lithic assemblage containing several different varieties of chert, silicified wood, chalcedony, quartzite, obsidian and a variety of igneous and metamorphic rocks (Schutt, 1997a, 1997b).

This considerable variety of materials makes the assemblage from FA2-13 ideal for assessing the influence of raw material type on stone tool life histories. In an effort to identify patterns in rates of use-wear accrual that can then be used as templates for the further analysis of this and other assemblages, a sample of ten flake tools from FA2-13 was examined following the same procedures used to assess all experimental tools. Building on my Masters research, this dissertation represents the next step in an ongoing program of research directed towards the development of a more dynamic interpretive model for studying lithic use-wear and its influence on subsequent tool use.

While limiting the scope of the present analysis to cherts and other similar materials, the specific types assessed include both those that are visually very similar to one another and those that are quite distinct. The aim was to try to identify both larger and smaller-scale differences in raw material properties that may influence rates of wear accrual and the nature of tool life histories.

The further point of analytical departure from my MA research involves the nature of the technology itself, specifically the time and energy invested in its production. My MA thesis focused exclusively on what is commonly described as 'formal' technologies, i.e. those that required moderate to considerable investments of energy in their production. The complex reduction histories of these tools, however, still pose certain obstacles to understanding the behaviours they represent. This is especially relevant when one considers that with each successive episode of use and rejuvenation, material volume is lost, specifically the portion or portions of tool edges and surfaces that would retain the bulk of evidence of earlier use.

Since the condition of an implement upon recovery from the archaeological record directly reflects manner of use just prior to final discard and any taphonomic alterations, and at best only indirectly any prior activities, it can be very difficult to evaluate the role of individual variables in the dynamic life histories of formal tools. In the case of raw material type, this problem is particularly pronounced. As a result, it was decided that a shift in technological focus was required. An examination of what have often been referred to as 'expedient' technologies redirected interest back to the basic dynamics of tool production and use. But before further discussing this shift in research attention, a few words regarding the nature of 'expediency' are warranted.

When considering the overall nature of a stone tool assemblage, many analysts initially make assessments regarding the time and energy required for its production and upkeep. Most often an assemblage is identified as representing a combination of 'formal' and 'expedient' technologies. This perspective has perpetuated a surprisingly narrow view of lithic technology and the role it played in prehistoric lifeways. This polarity in our understanding of stone tool production and use is based on the assumption of a correlation between tool formality and curation behaviour. A less restrictive conceptualization of tool formality and expediency underlies the present analysis of raw material variability as a determining factor of rates of wear accrual and the use-related reduction of the more 'expedient' technologies recovered from the FA2-13 site. This approach was taken in an effort to develop methods that can be applied to as wide a range of lithic technologies as possible and to further the goal of making lithic analysis as dynamic a field of inquiry as is the material it studies.

Chapters Two and Three of this dissertation will provide overviews of previous research in lithic archaeology and lithic resource studies in the American Southwest. These reviews are provided to establish this study's intellectual heritage, while at the same time illustrating the distinctiveness of its approach relative to its predecessors. Chapter Four provides a brief overview of lithic experimentation to set the stage for a discussion of the current experimental program. Chapter Five, along with cultural historical and ethnographic background information, details the methods and results of digital image analysis using the Clemex Vision software package. Chapter Six serves to compliment Chapter Five by describing the use of GIS analysis to more fully quantify the results obtained from image analysis. Chapter Seven explores the physical properties of the four raw materials under consideration through nanometer hardness testing in an effort to further clarify the results discussed in Chapters Five and Six. The eighth and final chapter brings all the various components of this study together to provide summary statements regarding the methods employed, results obtained and both their immediate and long-term implications.

This study's main objectives are to encourage both theoretical and methodological re-evaluation and to suggest some plausible alternatives to traditional analytical approaches. It is not my intention to discredit standard analytical practices, but rather to expand upon their utility and applicability. One of the greatest strengths any discipline can boast is the ability to regularly and systematically re-evaluate its methods and the theories that drive them.

CHAPTER 2: LITHIC ARCHAEOLOGY IN THE AMERICAN SOUTHWEST

Archaeological research in the American Southwest and prehistoric research done throughout most of the North American continent reflects a preoccupation with only selected portions of the archaeological record. This chapter examines the nature of this imbalance and the influence it has had on research in this area. The study of ceramics, their manufacture, decoration and use, has fascinated archaeologists for more than a hundred years, while other aspects of the prehistoric past have been the subjects of only occasional and sparing interest (e.g. Elson and Clark, 1995; Haury, 1976; Kidder, 1924,1932; Gumerman, 1988; Longacre, 1968; Hill. 1970). Chipped and ground stone tool analyses are relatively few in number when considered within the context of Southwestern archaeological literature as a whole.

These investigations have often taken the form of descriptive accounts of assemblage contents appended to more detailed ceramic analyses (e.g. Chapman, 1977; Christensen, 1987a; Davis, 1985; Gossett, 1982a; Linford, 1974; O'Hara, 1988; Schutt, 1997b). There have been a number of studies that involve different aspects of lithic technology, such as resource use and exchange, functionality as reflected by specific morphological variables, and modes of production. However, the implements being analyzed are typically viewed as static entities representing a relatively limited range of activities. As a result, they are viewed as being correspondingly limited in their ability to divulge cultural information about the prehistoric past.

The volume of lithic material recovered from archaeological sites often equals or exceeds that of most other forms of material culture. As such, lithic artifacts should be seen as a rich source of information that can serve as a solid basis for inferences about the past. The key to unlocking this potential is in how archaeologists approach their study. The adoption of a more dynamic, use-life oriented perspective of lithic technology, along with employing multiple forms of analysis within a single research project, represents a logical starting point.

Since at least the turn of the twentieth century there have been countless investigations into the prehistory of the American Southwest. The construction of cultural chronologies has always been one of the most enduring goals of archaeological research. Studies of pre-ceramic toolkits have commonly employed production techniques and morphological variation as the primary means of distinguishing one technological tradition from another in an effort to establish chronological sequences. As with studies in most other geographical areas, the projectile point is the main tool category used to define southwestern pre-ceramic toolkits and the cultural groups they represent. The outline shape and other point attributes in plan view continue to be the basis for identifying and distinguishing between Paleo-Indian, Archaic, and later cultural traditions.

Overall size and facial flake scar patterns, for example, are typically used to differentiate between Clovis and Folsom points. The scar patterns are particularly informative as they directly reflect method of manufacture and in particular hafting techniques. Clovis points are generally larger, with thinning flakes removed up to but not crossing over the mid-line of the point. Also, a channel flake extending from the base and covering approximately one third of the overall length was usually removed for hafting purposes (Bradley, 1993:254-256; Cordell, 1997: 79-82). Folsom points, on the other hand, are generally smaller with thinning flakes removed across their entire width, and a channel flake scar or flute covers almost the entire length of the tool (Frison, 1993: 241-244; Cordell, 1997: 83-84). The Clovis and Folsom Complexes contain the two most recognizable Paleo-Indian point types in the southwest and beyond, but represent only a small portion of the entire spectrum of projectile technologies attributed to peoples of this period.

The Archaic period, the latter portion of which being the temporal focus of this study, is characterized by less well-made implements, but still exhibits a wide range of variation in point form. At the larger end of the scale is the incipiently shouldered Jay point type that is diagnostic of the Oshara or Northern Tradition (Irwin-Williams, 1973: 4-6; Cordell, 1997: 108-109). The smaller end includes the often notched or stemmed Chiricahua Cochise point types that are associated with the Cochise or Southern Tradition (Moore, 1994: 473; Cordell, 1997: 109-110). Between these two extremes a number of additional point types are recognized that characterize various other regional traditions covering the entire southwest.

During the following Puebloan periods, semi-permanent or permanent architecture and ceramics supplant lithics as the most often studied components of material culture. As a result these latter have become the primary focus of archaeological research on this period, particularly following the formal establishment of the discipline during the first decades of the last century. These two types of remains were immediately recognized as being well suited to what was seen as the main task of archaeology at the time: the formulation and refinement of cultural chronologies. Culture history remains an important and active field of study to this day but is now generally thought of as an explanatory mechanism or framework rather than an end in itself.

Both ceramics and architecture are considered to be accurate barometers of late prehistoric culture change. Shifts in modes of construction and spatial organization of dwellings, as well as in the manufacture and decoration of pots, typically reflect changes in social, political, and economic structures over time and space. These components of material culture can therefore inform the archaeologist about mechanisms of adaptation, at social, technological, and even ideological levels. Both architecture and ceramics continue to serve as the underpinnings of currently used chronological sequences. Alfred V. Kidder (e.g. 1924, 1932, 1936b) through his work at Pecos Pueblo spearheaded the formulation of the widely recognized Pecos Classification, the first comprehensive chronological framework for the post-Archaic archaeological record in the Four-Corners area of the Southwest.

The Pecos Classification is predicated on the belief that particular types of structures and certain types of pottery directly reflect specific cultural traditions and therefore specific times and areas. Continued fieldwork and analysis have since revealed that the Pecos Classification is too general in that in does not take into account local and regional variations in cultural development. As a result, separate chronologies have been proposed for each of the four main culture areas in the Southwest: the Anasazi, Mogollon, Hohokam, and Patayan. The field of Southwestern ceramics has, over the years, produced one of the best-understood and most highly resolved sequences of cultural development.

Late prehistoric lithics have been used as a source of corroborating information in the construction of these chronologies. This has, however, been limited to the recognition of basic tool types comprising each toolkit and the differences in their overall form as they relate to function. The majority of lithic analyses from the early to middle parts of the twentieth century have followed the guidelines used by researchers such as Jeancon (1923) and further elaborated by Kidder (1932). Part of Kidder's (1932) work at Pecos Pueblo included the development of a system for assessing morphological and therefore functional variability among lithic artifacts. This system, which produced largely descriptive information, became standard lithic analytical technique. The quantitative data that was generated consisted primarily of length, width and thickness measurements used to refine the shape-based definitions of traditional tool categories.

The range of tool metrics used in general has, however, been slowly expanding over the last forty years. A number of lithic analysts, including Jelinek (1967), Lekson (1990) and Kamp and Whittaker (1999), have incorporated elements of the classificatory scheme for projectile points proposed by Lewis Binford (White, Binford, and Papworth, 1963). Jelinek, for example, considered such attributes as blade shape, number of notches, shape of notches and basal edge morphology in his analysis of projectile points from the Middle Pecos Valley, New Mexico (Jelinek, 1967: 90). Despite these advancements in analytical detail, the focus of a great deal of lithic research continues to reflect a pre-occupation with general morphological description as means of technological interpretation. A few recent studies have taken more involved approaches to lithic analysis. Whittaker (1984, 1987a, 1987b) has examined the projectile point assemblage from Grasshopper Pueblo, Arizona, in an attempt to isolate stylistic variation among these points across the site. While such studies are being carried out, they largely remain exceptions rather than the analytical rule.

Early History of Lithic Research in the Southwest

Southwestern archaeology in general can trace its beginnings back to the turn of the last century and an avid interest on the part of antiquarians and early researchers in the numerous highly visible Pueblo ruins. In contrast to the initial focus on these high profile remains, the earliest lithic studies were often the product of unplanned discoveries rather than of established research projects. As mentioned above, chipped lithic analyses have most often consisted of detailed descriptions for the purpose of ordering an assemblage into previously defined typological categories or to establish new ones as required. For late prehistoric occupations this was done to provide a source of corroborating data for the chronologies established using both architectural and ceramic materials.

A classic example of an unplanned lithic discovery that over time has helped foster the development of a thriving field of archaeological study is the discovery of the Folsom site (Cordell, 1997; Folsom and Agogino, 1975; Roberts, 1938). The exposure of extinct bison remains as a result of flood damage in an arroyo near Folsom, New Mexico, in 1908 eventually led to more formal investigations at the site during the 1920's (Cordell, 1997:68-72). The work done on this site was one of the primary catalysts that launched the study of the 'peopling of the New World' as an increasingly active area of archaeological inquiry (e.g. Chapman, 1977; Coffin, 1937; Frison and Bradley, 1980; Hester, 1972; Hibben, 1941, 1946; Haury, 1950, 1956, 1960; Irwin-

Williams, 1967, 1968, 1973, 1979, 1980a, 1994; Judge, 1970; MacNeish *et. al.*, 1994; Martin, 1973; Meltzer, 1993; Rogers, 1958; Roosa, 1956a, 1956b; Sayles, 1983; Vierra, 1994b, 1994c; Warnica, 1966; Wilmsen, 1965, 1970; Wormington, 1957).

Also among the earliest lithic studies are those that examined the methods and tools used for procuring lithic raw material. These were often based on the descriptions of expeditions undertaken at the turn of the last century by antiquarians and later in studies carried out by formally trained archaeologists (e.g. Bartlett, 1935, 1942; Bryan, 1950; Coffin, 1951; Fowke, 1892; Heizer and Treganza, 1944; Holmes, 1890a, 1890b, 1891, 1894, 1900, 1907, 1919; Phillips, 1900; Taylor, 1898; Wilson, 1897). W. H. Holmes has published detailed accounts of his early excavations at various aboriginal quarry sites. He described the nature of quarries themselves as well as the tools associated with them. The quarries often took the form of a series of large pits or depressions excavated into a natural or primary outcrop of siliceous raw material (Holmes, 1890a, 1891, 1894, 1907, 1919). The tools recovered from these quarry sites included both those used to extract the desired stone and the discarded debris from the preliminary stages of raw material reduction (ibid). This last group of artifacts also included a number of exhausted tools that were earmarked for replacement by new implements produced on the freshly mined raw material (ibid).

Analyses of Paleo-Indian and Archaic lithic assemblages often include greater detail than those dealing with Puebloan stone tools. The introduction of ceramics and larger-scale architecture has made the study of Puebloan lithic technology a secondary focus of archaeological research on this period. While the chronological importance of ceramics is unquestionable, it does not diminish the potential of lithic technologies to shed light on the past. The decrease in emphasis on researching stone tools is partly the result of an apparent shift from a combination of formalized and expedient technologies to generally more expedient tool production that occurred during the transition from the late Archaic to Pueblo periods and the perceived interpretive limitations of such technology. Task-specific sites, such as quarries, facilitated functional interpretations of the technology associated with them, making them desirable subjects for early archaeologists. More functionally complex sites, such as residential occupations, posed a greater challenge to lithic researchers, and as a result have proven more difficult to interpret in technological terms.

Alfred V. Kidder (1932) offered one of the first systematic accounts of the chipped lithic assemblage from a residential site. He provided detailed descriptions of all the traditionally recognized artifact categories as they were represented at Pecos Pueblo in Pecos, New Mexico. Kidder recognized three general categories of flaked stone tools:

> "The first category represents the greatest perfection of manufacture, for it comprises implements all of whose surfaces have been worked by secondary chipping...The second category comprises implements which retain unmodified one or more of the faces that were produced when the parent mass of stone was being broken up...Implements of the third category are flakes or slivers of stone produced by the primary breaking up of the parent mass and put directly into use without any secondary chipping..." (Kidder, 1932: 13-14)

He subsequently further subdivided the Pecos assemblage according to inferred function and then in turn by morphological variation within each recognized functional category. This approach to categorizing chipped stone tools and stone tools in general has become standard methodology in the Southwest, and in archaeology in general. Richard B. Woodbury (1954) followed these same procedures in his report on the stone tools recovered during the Awatovi Expedition in northeastern Arizona. As Kidder did with the Pecos Pueblo material, Woodbury focused most of his attention on projectile points, recognizing a greater number of subdivisions within this category than in any other lithic category (Woodbury, 1954: 120-142). Despite a traditional dependence on gross morphology to recognize functionally different tool types, he did acknowledge a need for more detailed examination of tool edges for evidence of use-related wear. He states:

> "As an aid to deciding which of the points and blades in this collection might have been used as knives or scrapers, each one was carefully examined for evidence of wear along its edges." (ibid: 142)

However, he limits these examinations by using only a 10x-magnification hand lens as well as by focusing only on the points rather than on the assemblage in its entirety.

Arthur Jelinek (1967) helped expand the approach made popular by Kidder by increasing the number of metric and morphological variables being considered (ibid: 88-114). This expansion reflects the direct influence Lewis Binford's proposed classification system for projectile points (White, Binford, and Papworth, 1963) has had on lithic research. Binford advocated detailed quantitative assessments of these implements to gauge more precisely their variability in functional terms. Jelinek (1967), through his work with material from the Middle Pecos Valley, New Mexico, recognized 15 blade edge/base edge morphological configurations and 28 hafting element configurations among the recovered projectile points (ibid: 94-95). By comparison, and as further illustration of the general preoccupation with projectile technologies, he recognized only four edge morphologies for the end scrapers he studied (ibid: 112). Using such physical traits, Jelinek identified several temporal and spatial sequences of point types (ibid: 103-109). Although they represent the full extent of variation exhibited by these artifacts, their variability is treated as being indicative of purposeful differences in their manufacture rather than, at least in part, the effects of use and maintenance. This focus on stone tool production to the relative exclusion of subsequent use was often a hallmark of early lithic analyses.

The same analytical preoccupation can also be observed in more problem-specific studies of stone tools. Franklin Fenega (1953) re-examined a large number of lithic assemblages from the Southwest and other regions of the United States west of the Mississippi River. He chose to re-visit the work initiated by Kidder (1932, 1938) dealing with the perceived correlation between projectile point size and inferred function (Fenega, 1953: 309-310). He decided on the variable of tool weight as a means of testing Kidder's findings concerning the size/function relationship. He found that:

> "Within each of the specific cultural manifestations discussed, projectile point weights cluster about one of two modes which have been designated as the small point tradition and the large point tradition." (ibid: 322)

He also re-established a correlation between point size/weight and the type of hunting equipment used by each culture. Earlier in prehistory the predominance of larger projectile points is associated with larger devices such as the atlatl. Later prehistory is characterized by smaller point varieties in keeping with the advent of bow and arrow technology (Fenega, 1953: 322). The assumption being made by Fenega and by Kidder before him is that the size of a particular point was solely a reflection of the original design envisioned by the prehistoric knapper. This, however, may not have always been the case as size, as well as function, may have changed over time as points were used and periodically refurbished.

Although the majority of the early lithic literature revolves around projectile technologies, various authors have also studied other categories of stone tools. Kenneth Honea (1965) examined the process of scraper production and assessed their resulting morphological variability. Honea's study examined both primary and secondary stages of initial scraper blank reduction as a way of distinguishing between different types of scraping tools. He wrote:

> "Discussed in detail are the various flaking techniques by which scraper blanks were produced and the manner in which these are retouched into scrapers." (ibid: 25)

He first emphasized the basic distinction between scrapers exhibiting intentional retouch and scrapers that only show retouch produced through use (ibid). The remainder of Honea's paper focused solely on the first of these two categories. The production of intentionally retouched scrapers begins with the initial reduction of the flake blank followed by secondary retouching or modification of the flake margins. It is this secondary retouch that determines the form of the finished tool. In his discussion of this process Honea acknowledged that detailed inspection of the retouch on scraper margins can yield information not only on the nature of their production but also on the manner of their ultimate use (Honea, 1965: 26). He did not, however, pursue this topic beyond recognizing its potential in interpreting how these implements were most likely used.

To further the main goal of his study Honea reviewed the principles of stone tool manufacture as they relate to scraper production (ibid: 26-35). This all led to the presentation of his proposed morphological typology for scrapers from the Southwest (ibid: 35-39). Despite Honea's acknowledgement of the possible effects of use on tool morphology, he did not consider it a significant source of variability and therefore did not explore how manner of use may have influenced scraper form over time.

One of the earliest efforts at considering a broader system of causality in the determination of tool form was W. James Judge's (1970, 1973) research on physical variation in Paleo-Indian stone tool technology. His 1970 study focused on the taxonomic debate surrounding the division between Folsom and Midland projectile points from the late Paleo-Indian period. Judge applied a systems analysis approach to this issue in an attempt to refine our understanding of the technological differences between these two point types. His analysis involved the recording of several morphological attributes, along with those related to, and therefore considered diagnostic of, different reduction stages (ibid: 141-151). Judge also conducted wear analyses at both the macroscopic and microscopic levels in order to document the presence or absence of discrete wear traces on tool edges and surfaces as a means of functional inference (ibid: 151-160).

His study served to formulate a number of testable hypotheses regarding Paleo-Indian technology, including hafting techniques (ibid: 325), as well as more general technological trends across the traditionally recognized Folsom, Clovis, Belen and Cody cultural complexes (ibid: 329). Judge was able to recognize evidence for long-term change in tool form and function and thus formulate what he refers to as the *implement development model* of increasing technological specialization (Judge, 1973: 329), but he did not consider how these implements might have changed during the course of their own use-lives.

Judge's perspective on lithic technology was formalized a few years later by Michael B. Schiffer's (1976) behavioural archaeology. R. G. Elston (1986) further expanded upon this approach as part of his dissertation. He conducted what he described as a structural analysis of stone tool production using the concept of manufacturing trajectories similar to that used by Judge (1970) and Schiffer (1976). While progress continues to be made, these innovations have yet to take permanent root in Southwestern lithic studies.

The next section will examine the trends that have characterized the last twenty-five years of lithic research in the Four-Corners area. These trends have continued to promote the research strategies that have come to define Southwestern lithic analyses, and at the same time support the pursuit of more innovative avenues of investigation to maximize the amount of cultural information that can be recovered through the study of chipped stone tools.

Recent Trends in Southwestern Lithic Studies

Over the past twenty-five years archaeological research in the American Southwest has simultaneously continued to emphasize the very issues on which the discipline in this area was founded and foster the development of studies covering an increasingly wider array of research questions (e.g. Adovasio, 1993; Bockley-Fisher, 1990; Brown, 1982a, 1982b, 1996; Christenson, 1987a, 1987b; Del Bene and Branchard, 1994; Glascock, Kunselman and Wolfman, 1999; Green, 1985; Haynes, 1993; Jacobsen, n.d.; Moore, 1994; Ozbun, 1987; Parry, 1987a, 1987b; Post, 2002; Simms, 1988; Warren and Phagan, 1988; Willig and Aikens, 1988).

Paleo-Indian and Archaic Studies

The precise timing of the first arrival of human populations on this continent continues to pre-occupy the minds of many Paleo-Indian researchers, with classification and chronology frequently serving as an interpretive framework for this debate (e.g. Adovasio, 1993; Adovasio, Donahue, and Stukenrath, 1990; Bradley, 1993; Haynes, 1993; MacNeish, Cunnar, Jessop, and Winter, 1994; Meltzer, 1995; Stone, 1999). In the Southwest, as in other areas, these investigations range from general typological assessments (e.g. Bradley, 1993) to alternative approaches to chronological ordering (e.g. Haynes, 1993). Bruce A. Bradley offers a re-evaluation of traditional functional stone tool typologies in light of an increasing appreciation of the dynamic nature of lithic assemblages in terms of both production and subsequent use. He states:

> "No longer are *finished tools* simply classified and compared. Gone are the days of simple functional typologies. It is now generally accepted that flaked stone artifacts became part of the archaeological record as the result of manufacture, use, reuse, discard, and natural site formation processes." (Bradley, 1993: 251)

Although he acknowledges the highly variable nature of lithic technology, Bradley still adheres to a largely typological perspective. Vance C. Haynes Jr. (1993), on the other hand, attempts to correlate the transition from Clovis to Folsom technology with climate change using a geochronological approach. He concludes that hydrogeological, stratigraphic and artifactual data collectively indicative of climate change and resulting technological adaptations may have contributed to the extinction of Pleistocene megafauna (ibid: 234).

Use-wear analysis has also been applied to Paleo-Indian technology (e.g. Frison, 1979, 1989) to refine functional, and therefore taxonomic, interpretations. Examining implements recovered from the Colby site, Marvin Kay (1996) set out to determine if traditional functional interpretations of big game kill tools, "often assumed but not confirmed by reference to artifact form and archaeological context" (Kay, 1996: 315) can be confirmed through more empirical evaluations. His study showed that the combination of macroscopic, microscopic, and contextual data demonstrates that some of these tools were heavily curated and that trace evidence of successive episodes of use can be recognized and distinguished from one another (ibid: 341). Kay also suggests that beyond the variation associated with repeated use and rejuvenation, the points from the Colby site are typical of the Clovis culture, but sufficiently distinct in their own right to be considered a separate subtype (ibid: 342). His study reflects a trend towards greater recognition of variability in tool form, not only as a result of reduction during manufacture, but continuing through use and maintenance.

Archaic toolkits have also been the subject of recent archaeological inquiry (e.g. Beckett and MacNeish, 1994; Del Bene and Branchard, 1994; Hicks, 1994; Moore, 1994; Parry, Smiley, and Burgett, 1994; Schutt, 1980). Paralleling the trends in Paleo-Indian research, studies focusing on Archaic materials also include the more traditional subject of classification as well as more innovative analytical alternatives to standard lithic research. An example of a more traditional study is Roger A. Moore's (1994) re-assessment of the standard approach to Archaic projectile point classification, using several Oshara Tradition collections from northern New Mexico (ibid: 456).

He employed previously published chronometric data in tandem with his own analysis of 365 projectile points from his study area (ibid: 468). Using eleven metric and eight morphological variables, as well as three provenience designations, he found that the types originally described by Irwin-Williams (1973) are indeed distinct categories (ibid: 474). Moore also noted that a certain degree of variability exists within each of these categories, which may be indicative of either temporal or regional variation (ibid). While he does recognize the potential effects on point morphology of regional differences in hunting practices, he does not consider the possible typological implications of changes in point form and function over the course of individual tool use-lives.

Patricia A. Hicks' (1994) study of the lithic material from Arroyo Cuervo and Abiquiu Resevoir in northern New Mexico, alternatively, explores the potential of debitage analysis as a means of identifying temporal variations between assemblages and the technologies they represent (ibid: 478). She found that certain debitage attributes could be temporally sensitive including heat treatment and flake type (ibid: 504), but cautions that the relationships between such attributes are quite complex, requiring they be carefully considered prior to identifying any general trends over time (ibid: 520).

In his study of Archaic hunter-gatherer mobility, Bradley J. Vierra (1994c) adopted a regional perspective choosing northwestern New Mexico as his geographic focus. He used ethnographic data regarding contemporary hunter-gatherer seasonal rounds and territory sizes in conjunction with the spatial distribution of both non-local archaeological lithic raw materials and human occupations as a way of delineating prehistoric mobility patterns (ibid: 121). Vierra, for example, suggests that towards the end of the Archaic there was likely the beginning of a shift from primarily seasonal residential movement to increasingly logistical patterns of mobility, indicating an increase in the economic significance of cultigens as part of larger subsistence strategies (ibid: 140).

A considerable amount of Late Archaic lithic research has focused on this Archaic-Formative transition, particularly on the shift from hunting and gathering to agricultural subsistence strategies (e.g. Doyel, 1984; Huckell, 1988, 1996, 1998a; Huckell and Huckell, 1984; Matson, 1991; Roth, 1996a/b; Whittlesey and Ciolek-Torrello, 1996; Wills, 1988a/b; Wills and Huckell, 1994). Along with changing mobility patterns and increased sedentism, shifting technological priorities also characterize this cultural shift. Over time a number of analytical tacks have been taken in attempts to further our understanding of the processes that operated to both induce and facilitate these changes. M. Steven Shackley (1988, 1992, 1996) has used the *Southwest Archaeological Obsidian Project*; a long-term effort to identify the geological source locations of prehistorically exploited obsidian, to assess changes in mobility patterns throughout the Archaic period. He found that, compared to Middle Archaic tool assemblages, those dating to the Late Archaic contain a narrower range of obsidian types, suggesting a decrease in overall group mobility toward the end of the Archaic period (ibid, 1996: 11).

Like Vierra (1994), Barbara J. Roth (1996b) examined land use strategies in the Late Archaic of the Tucson Basin of southern Arizona. She, however, evaluated the patterns of settlement in the northern Tucson Basin through functional assessments of recovered lithic technologies. Comparisons of stone tool assemblages from higher elevations within the basin versus those from sites on the floodplain suggest differing land use strategies in each area. The higher altitude implements indicate shorter-term logistical resource use, whereas the tools from the floodplain reflect longer-term occupation. This mix of technological strategies is indicative of transition towards an increasingly sedentary way of life (ibid).

Puebloan Studies

A set of studies that exhibit traits of both traditional and more recent trends in classificatory research are those that have examined the lithic assemblages recovered from several field seasons of excavation at Arroyo Hondo Pueblo in north-central New Mexico (Bonney, 1971, 1972; Linford, 1974; Phagan, 1993). The long analytical history attached to the Arroyo Hondo collection offers a rare glimpse into how even relatively minor changes in methodology and perspective over time can profoundly affect interpretation. The earlier analyses by Rachel Bonney (1971, 1972) and Laurance Linford (1974) focused primarily on the classification of the Arroyo Hondo tools as a means of interpretation. Bonney began by distinguishing between unifacial, bifacial, and use-related retouching of tool surfaces and margins (ibid, 1972: 15). She then used these distinctions to sub-divide all of the traditional tool categories into several series of specific morphological types (ibid: 61).

Bonney then proceeded to evaluate the distribution of chipped stone tools throughout the pueblo relative to other forms of lithic technology, including ground stone tools and ceremonial items. In addition to these preliminary analyses, Bonney also consulted the ethnographic literature in an attempt to further flesh out some of the interpretations she made regarding these tools. Although she began her analysis by applying a very traditional or qualitative, typological approach, she did incorporate additional analytical tacks and external sources of information to further illuminate the initial observations made from the tools themselves.

Laurance Linford (1974) revisited the stone tool assemblage from Arroyo Hondo Pueblo, principally to incorporate the material recovered during the 1973 field season into the pre-existing collection, but also to re-evaluate and expand upon some of Bonney's preliminary results. More recently Carl Phagan, in his 1993 summary report on the Arroyo Hondo lithic assemblage, examined not only his predecessors' studies but also their unpublished research notes, as a means of integrating their work with his own evaluations (Phagan, 1993: 205-207). He began the integration process with following perspective in mind:

> "Systems for analyzing stone tools in Southwestern assemblages have traditionally been largely descriptive rather than classificatory, with categories used primarily for simplifying the description of large collections. This is not bad, but neither is it adequate for responding to the kinds of problems archaeologists address today. More recent analytic systems have begun to reflect such concerns." (ibid: 208)

He further recognized the tendency in Southwestern lithic research to emphasize the analysis of projectile points over other categories of flaked stone tools (ibid: 211). However, since the earlier reports on the Arroyo Hondo material shared this pre-occupation, Phagan followed suit and made projectile points the primary focus of his own study. He saw the need to refine the original typologies, expanding their strictly descriptive nature to include an interpretative component to elicit potential behavioural meaning (Phagan, 1993: 212).

The best way to accomplish this task, according to Phagan, was to consolidate a number of previously recognized tool types into more general categories. He decided to use, for example, "...only the presence or absence of notches and/or stems...as criteria to divide projectile points into two large classes" (ibid). He relies instead on comparisons of assemblage components to gain insight into the behavioural patterns that produced the Arroyo Hondo assemblage. These comparisons take the form of artifact type ratios, including all flakes per core and all flakes per flaked stone tool, as well as ratios dealing with tool distribution throughout the Pueblo (ibid). Commenting on the potential of such ratios he cautions that they permit only the most general level of interpretation and that individual components used in formulating these ratios must be comparable in terms of how tool proveniences are defined (Phagan, 1993: 213). Despite these qualifying remarks what is not fully considered is that patterns of tool discard do not necessarily reflect the full range of prehistoric use behaviour. As a result, the type of ratios that Phagan uses may be insufficient for fully interpreting patterns of tool use over time.

Although Phagan's work on the Arroyo Hondo lithic assemblage was somewhat limited by the nature of his predecessors' work, his research on other sites (Phagan, 1979, 1980a, 1980b, 1982a, 1983, 1986, 1988a, 1988b; Phagan and Hruby, 1984; Phagan and Maloney, 1981) reflects a trend towards more sophisticated approaches to lithic analysis. The Dolores Archaeological Program (DAP) has produced analyses that have examined the nature of stone tools from a number of different perspectives. Phagan and Thomas H. Hruby (1984) produced a manual that served as the organizational and interpretative template for all subsequent DAP lithic studies. This guide covers all aspects of lithic research including general procedures for documenting an assemblage, analyzing the resulting data and subsequently classifying the implements under study.

Phagan and Hruby, modifying the pre-existing DAP system of analyzing reductive technologies (e.g. Moore, 1980), incorporated a wider range of variables in their approach. These variables include raw material type, grain size, morpho-use category, and several variables relating to the nature and extent of purposeful reduction (Phagan and Hruby, 1984: 153, *Figure C.1, Appendix C*). They also developed similar approaches for studying flaked stone debris, non-flaked stone artifacts, and bone/shell implements. Despite all of the variables taken into account by Phagan and Hruby, what they did not incorporate into their analytical system is the means to evaluate how stone tools change in shape, and often in function, through several cycles of use and maintenance. As a result there is little interpretative recourse within their system for determining how the variables they use may reflect these changes.

Phagan applied the procedures he and Thomas Hruby established in several subsequent DAP reports (e.g. Phagan, 1986; 1988a; 1988b). His 1986 report on the reductive technologies from the DAP study area, produced as part of the work being done by the Reductive Technologies Group (RTG), represents a direct application of that system. He summarizes this tack as follows:

> "The DAP (Dolores Archaeological Program) Reductive Technologies Group has frequently used a 'profile' of lithic assemblage characteristics to compare and interpret large data sets" (Phagan, 1986: 103)

He found that these lithic profiles fell into one of two distinct site type groups: limited activity and Group A sites and seasonal, hamlet and village sites (ibid: 114). These profiles reflect characteristic subsistence strategies associated with certain site types (mobile hunter-gatherer vs. sedentary horticulturalist/agriculturalist), and therefore the particular activities involved in their practice. Phagan also investigated patterns of raw material use, and the labour input cost of chipped lithic toolkit production and maintenance. These analyses offer some detailed insights into the relationship between toolkit composition and site type in the DAP study area, but they do so from the rather narrow perspective that stone tools were a static medium exhibiting minimal variability over the course of individual use-lives.

Phagan refined his analytical approach even further with his typological study of the projectile points recovered from the DAP study area (Phagan, 1988a, 1988b). The first phase of his analysis involved the statistical derivation of a point typology based primarily on variables of gross morphology (ibid, 1988a: 14-19). Both factor and multivariate analyses were applied to the resulting data set to formulate type and subtype identifications, as well as to evaluate the interpretive utility of these categories and of the classification as a whole. His analysis recognized five general types of projectile points, each consisting of several subtypes. The first of these types, referred to by Phagan as *Type S-1*, is described as follows:

> "Stems are generally narrow and straight to slightly contracting, although 1 subtype (S-11) has slightly expanding stems, while a second subtype (S-13) has distinctly contracting stems...All 4 subtypes have a very pronounced overlap of the blade and stem or base portion of the point, which produces a low notch angle. The notch opening angle is narrow, although not as extreme as type S-5. Blade margins are long and quite straight." (Phagan, 1998a: 40)

The other four point types are described in analogous terms (ibid: 40-41). Reflecting on the first part of his analysis, Phagan posed the question: are these types "...simply arbitrary or [are they], as hoped, also archaeologically useful" (ibid: 42, in brackets added)? In an effort to answer this question, he plotted the distribution of the five statistically derived point types by phase, subphase, temporal period, site type, and among individual sites (Phagan, 1998a: 42-50).

He found that, as expected, these distributions largely paralleled patterns of excavation intensity and prehistoric population density estimates, but he did recognize that certain point types tended to cluster within specific phases, time periods, or individual sites (ibid). He left an assessment of the significance of these findings to future researchers, and turned his attention to the issue of the relative interpretative value of statistically determined versus intuitively derived typologies. Phagan suggested that statistically defined typologies are preferable to intuitively derived ones due to their "...greater level of objectivity...communicability, and ... repeatability" (ibid: 87).

Using the same DAP dataset from the first phase of his analysis, Phagan had three different researchers develop intuitive typologies and selected the two that most closely resembled his statistical classification for further evaluation. Using both univariate and multivariate analyses to quantitatively compare their relative effectiveness (ibid, 1988a: 87), he found that the two intuitive typologies were generally inconsistent in their ability to correctly predict discriminating variability at both the type and subtype level compared to the statistically derived typology (Phagan, 1988b: 109). This result, in part, reflects each researcher's level of familiarity with the variables that were used, qualifying any assessment of superiority between either the two intuitive typologies or the intuitive typologies and their statistical counterpart (ibid).

To further evaluate these three classifications Phagan performed the same distributional analyses with the two intuitive typologies as he did with his statistically derived classification (ibid: 110-128). The results for each intuitive system differed to varying degrees depending on the spatial or temporal units used, but they do not by themselves suffice as a basis for determining which one of these systems is inherently more reliable (ibid: 128). Phagan, however, concluded that of all three typologies under consideration:

> "The statistically derived types and subtypes have consistently demonstrated equivalent or superior quantitative definitions when compared with the intuitive categories on a standard set of 14 shape variables. Further, [statistical] subtypes within types demonstrate a greater consistency of definitional distinction than do the intuitive subtypes." (ibid; in brackets added)

He recognizes that *analytical utility* can only be tested through the practical application of all three typological systems to many different datasets in addressing a wide range of research questions in various temporal and spatial contexts. Also required, according to Phagan, is the development of a systematic means of evaluating the relative 'correctness' of the various results (ibid, 1988b: 128-130). A further complicating factor that Phagan did not consider in his study is how projectile point shape may have changed as a result of use and repair, and how these changes can be misinterpreted as indicating the presence of two or more distinct types. Phillip D. Neusius' (1988) low-power approach to the use-wear analysis of assemblages from selected DAP sites represents a first step in addressing this issue.

As a result of the relatively expedient nature of Puebloan chipped stone tools, use-wear analysis has seldom been applied to these implements (e.g. Berg, 1993; Nelson, 1984). Neusius' contribution to the Dolores Archaeological Project (1988) is therefore a fairly rare example of a micro-wear study of a number of Anasazi lithic assemblages. A low-power approach was adopted by Neusius in part as a response to constraints of time and finances, but also as a means of assessing larger assemblages in as efficient a manner as possible (ibid: 209). He used three groups of attributes to interpret the functional variability of the tools being studied. The first consisted of basic provenience and identification data and the second and third of variables developed by both Neusius and others (ibid: 211). These last two groups include such attributes as edge and facial rounding, polish, and striations, as well as a number of variables dealing with use-related flake scar production (ibid: 212).

Based on all three datasets, identifications were made for each implement including activity type and contact material. The activities recognized cover the standard range of subsistence-related tasks from cutting or sawing through scraping or planing to various forms of grinding. The contact materials were identified as either soft, medium, or hard, and then further differentiated as animal or vegetable, and organic or inorganic (ibid: 212-213). One of his first observations was that the expectation of a smaller proportion of situational or more expedient tool forms on seasonal sites (Schlanger and Harden, 1983) was not only not met, the opposite proved most often the case (Neusius, 1988: 229-230).

The remainder of Neusius' use-wear analysis focused on task performance variability on permanent Anasazi habitations during the Basketmaker III to Pueblo I transition. Although Neusius did consider in some detail the uses to which chipped stone tools were put and their distribution within and between habitation units, what remains unexplored is how these uses directly affected tool form over time. The selection of relevant measures to gauge use-related changes in tool form and their incorporation into standard use-wear analyses will enhance our understanding of flaked stone tool variability and enable us to refine our methods of interpreting changes in production and use over time.

Caryn M. Berg (1993) applied high-power microwear analysis to the expedient lithic technology of Elden Pueblo in the Sinagua Culture Area of North-Central Arizona. She set out to assess both tool function as a reflection of subsistence activities, and the applicability of high-power use-wear analysis to the study of informal tools (ibid: ii). She found that examination of use traces on expedient technologies is a worthwhile and informative analytical approach (ibid: 68-69). This result echoes the sentiments of other analysts (e.g. Vaughan, 1985), but use-wear analyses of expedient technologies remain relatively few and far between. Her analysis of the Elden Pueblo material revealed evidence of meat and hide processing, indicating that hunting was still an important part of the prehistoric occupants' subsistence strategy (ibid: 69-70). Berg also recognized the significance of raw material variability as a factor in polish formation (ibid: 70), but she did not explore the impact of such variability on inferences regarding the intensity of use and therefore on assessing the relative contributions of different activities as part of an overall subsistence strategy. Despite prevailing attitudes regarding expedient technologies, these implements can be a significant source of both cultural and technological information. They can even serve as something of a methodological proving ground for refining analytical techniques as a way of enhancing the potential of lithic research in general.

A more pronounced departure from traditional approaches to lithic analysis is represented by the work of John C. Whittaker (1984, 1987a, 1987b). Since his later papers are based on his doctoral research and thus cover the same material, his dissertation (Whittaker, 1984) will be the sole focus of the present discussion. Using detailed evaluations of point form and flake scar patterning on both archaeological and experimental specimens, he set out to assess the variability generated by the abilities and habits of individual lithic artisans at Grasshopper Pueblo. These variations, according to Whittaker, can be used to identify "...patterns of organization, specialization, and exchange" (ibid: xiv) across the Pueblo. He writes:

> "If individual craftsmen can be traced, it is sometimes possible to see how they cooperated, specialized, and participated in the economic and social life of their communities." (ibid: xv)

Whittaker recognized that chipped stone tools have the potential for shedding considerable light on prehistoric systems of cultural organization and need not be relegated to the interpretative confines of traditional typological studies.

Combining data derived from experimental reproduction of Grasshopper Pueblo projectile technologies with those generated from analysis of the archaeological assemblage itself, Whittaker was able to recognize certain manufacturing regularities among different sets of these tools. He suggested that these regularities might reflect stylistic variations associated with the work of different knappers. He identifies two general sources for these variations: conscious selection of preconceived design parameters, such as particular shapes or dimensions, and the often unconscious effects of individual "...skill, and motor habits" (ibid: 144).

Whittaker decided to focus his examination on observed variability within the Small Triangular Point Complex at Grasshopper Pueblo. He selected this particular assemblage subset for it's general uniformity in terms of raw material use, reduction technology, and intended function, thereby largely neutralizing these characteristics as sources of non-stylistic variation (ibid: 147-149). Restricting the spatial context of his study to burials and caches, as well as a few complete point assemblages from selected rooms, the resulting samples were subjected to discriminant analyses to assess which attributes best reflect stylistic variation. These traits were then further tested through quantitative comparisons with experimentally replicated points to determine if they can be attributed systematically to the same sources of variation in both cases and therefore be considered as reliable indicators of differences in individual workmanship (ibid: 149-152).

Whittaker initially identified 13 likely sets of projectile points from 13 different contexts, most of which were burials (ibid, 1984: 153, *Table 7.1*). The attributes selected for testing as indicators of set membership include general metrics and flake scar orientation, which he defined as being:

> "...measured with respect to the long axis of the point. Zero was at the base and 180 degrees at the tip, thus scars which slanted upward fell into intervals less than 90 degrees, while those running down toward the base measured as greater than 90 degrees." (ibid: 173)

To generate attributes for testing, these measurements were first considered collectively as a single dataset and then separated into right and left edge categories. Several statistical values were then generated in an attempt to isolate any patterning in flake scar production relating directly to the habits of individual knappers (ibid: 175-176). Both the general metrics and the flake scar angles were subsequently subjected to discriminant analysis to identify groups of points produced by the same artisan. These analyses incorporated both archaeological and experimental specimens in order to verify and ensure the integrity of attributes used as indicators of individual workmanship at Grasshopper Pueblo.

Whittaker (1984) found that, in terms of general metrics, both the archaeological and experimental point sets exhibited significant intra-set regularity and inter-set variation (ibid: 195). Although attributes varied in their effectiveness as a basis for discriminating different sets of projectile points, the majority "...were of some use; most distinguished at least some sets" (ibid: 197). He also suggests that despite the added complexity of a single knapper potentially having produced more than one type or style of point, the "...contextual separation of the sets and the relatively small size of the sample of sets..." (ibid: 199) minimizes the likelihood of this having been the case.

While attributes relating to point form almost certainly represent conscious decisions made by the knapper, those relating to flake scar orientation are more likely the products of sub-conscious habit (ibid: 200). The effectiveness of these attributes in differentiating between point sets is therefore not quite as pronounced as that of general metrics (ibid: 201), yet their analysis still produced some interesting results. Whittaker writes:

> "... while flake scar angle distributions were similar on both faces of a point, the left edges consistently differed from the right edges...scars on the right edges...tend to be oriented at higher angles than those on left edges...In terms of the appearance of the point, scars on the left edges tend to be closer to horizontal, while those on right edges tend to slant downwards slightly." (ibid: 210)

He initially considered the possibility that this tendency was related to the handedness of each knapper, but testing of the experimental point sets showed this relationship to be problematic at best. Independent of the handedness of each individual knapper, variations in flake scar orientations seemed to be associated more systematically with how the point was held relative to the flaking tool. As a result, the angles at which flake scars were produced relative to the long axes of the points often varied independently of handedness (Whittaker, 1984: 215, *Figure 7.19*). Like their experimental counterparts, flake scar orientations on the Grasshopper points also do not consistently reflect handedness, but Whittaker does not rule out the potential of this variable to distinguish between the products of right and left-handed knappers in other archaeological contexts (ibid).

Despite the less than consistent performance of flake scar measurements, the attributes used by Whittaker were largely able to distinguish the products of different knappers. This was, in part, due to the presence at Grasshopper of what he described as *limited* or discrete physical contexts, e.g. burials, that separate groups of artifacts that can be inferred to be the products of different artisans (ibid: 232). He concludes that the:

> "Lithic crafts at Grasshopper were probably similar in their organization to crafts in the historic Pueblos, with no centralized organization of production or distribution. Some individuals were probably part-time craft specialists, but most people would have produced most of their own tools, and there is no evidence for any small group of highly specialized artisans living primarily by the exchange of their craft products." (Whittaker, 1984: 329)

Apart from the limitations of discriminant analysis (ibid: 232, 329) and the perennial issue of adequate sample sizes, another complicating factor not taken into consideration by Whittaker relates to how both general metrics and flake scar orientation may have been affected by technological differences between the production and subsequent maintenance of points. Some of this potential variability may be explained by the designation of some specimens recovered from burials as grave goods, specifically those showing little or no evidence of use prior to their deposition, but this explanation would not necessarily be applicable to all tools in all contexts. Not only is further study regarding the general nature of individual variation in stone tool production necessary, as stated by Whittaker (ibid: 329), but additional research on the technological differences between tool production and maintenance and how each influenced tool form over time, is also needed.

Along with these more innovative approaches to chipped lithic analysis, numerous traditional accounts of stone tool assemblages continue to be published (e.g. Bernard-Shaw, 1983; Bradley, 1997; Brown, 1982b; Cameron, 1997; Davis, 1985; Kamp and Whittaker, 1999; Lekson, 1990, 1997; Parry and Christenson, 1987; Parry and Speth, 1984; Sell, 1997; Shelley, 1983; Windes and Cameron, 1981). William Davis (1985) produced a standard typology of the projectile points as well as descriptions of the other tool types recovered from White Mesa, Utah. He based his categories and descriptions on length, width and thickness values to the exclusion of any other variables (ibid: 275-309). He also included a short evaluation of collected debitage, including identification of traditional flake types and some of their basic metric attributes (Davis, 1985: 302-309).

Stephen Lekson (1990), in describing the excavations at the Saige-McFarland site in southwestern New Mexico offered a brief summary of the flaked stone tools recovered from this Mimbres phase occupation (ibid: 60-65). Lekson's primary focus is on the distribution of raw materials used in tool production, but he also included some general comments on certain tool categories, particularly projectile points, and their spatial patterning across the site (ibid: 60). Katherine Kamp and John Whittaker (1999), as a final example, examined the material culture of the Northern Sinagua of Lizard Man Village, near Flagstaff, Arizona. Their analysis of the chipped lithics and associated debitage from this site subdivided the point assemblage into recognized types and subtypes (ibid: 83-85). They also considered the chronological relationships, uses, and spatial distributions of both implements and raw materials (ibid: 85-87). Following a standard analysis of chipping debris, they explored patterns of core reduction intensity as a function of raw material type (ibid: 91-92). The remainder of their study includes very brief descriptions of other flake tools and a general summary of the temporal and spatial distribution of all lithic artifacts from this site (ibid: 94-97). These studies demonstrate that the analytical goals of lithic archaeology in the Southwest, established in the first half of the twentieth century, continue to be pursued to this day, albeit using more sophisticated methods. In fact, research on all periods of Southwestern prehistory can be characterized by this gradual increase in the variety of analytical approaches used.

Despite the progress that has been made in flaked stone tool analysis over the last twenty-five years, there remains a great deal of unrealized potential for interpretation among these implements. Although more sophisticated studies of use-wear traces, stylistic variability and typology have been carried out in various areas of the American Southwest, they must be considered as largely preliminary in nature. There are a number of problems these studies still do not fully address. In particular, the effects of use on tool form over time were not discussed despite their likely influence on various aspects of their respective results.

Deborah I. Olszewski and Alan H. Simmons (1982) discussed prevailing attitudes towards Puebloan lithic technology, which are equally applicable to all periods of Southwestern prehistory. They point out the need to study entire lithic assemblages, not just those artifacts recognized commonly as tools (ibid: 113-114). They are, however, too quick to dismiss the value of use-wear analysis to Southwestern lithic studies (ibid). This may be partly a product of the intellectual environment in which they wrote their paper, as in the early 1980s use-wear research was still very much in its infancy in the western world. The same could perhaps be said about the state of this area of investigation today, but significant methodological improvements have been made over the last twenty years (e.g. Kimball *et al.*, 1995; Levi-Sala, 1986; McBrearty *et al.*, 1998; Newcomer *et al.*, 1986, 1987; Stemp and Stemp, 2001, 2003; Vaughan, 1985). As a result, the study of trace wear has a great deal more to offer Southwestern archaeology today than it did in 1982, especially where more expedient technologies are concerned. The next chapter will begin with an overview of lithic resource research and then take a closer look at lithic resource studies in the state of New Mexico in order to provide more detailed contextualization for the present study.

CHAPTER 3: LITHIC RESOURCE STUDIES

The following discussion focuses on raw material resource studies with particular emphasis being placed on the work done in New Mexico. As such, it serves as both a foundation and point of departure for this dissertation in an effort to fully contextualize the impetus for and results of the present study. Research into the procurement and use of chipped lithic raw material has been a mainstay of archaeological research for more than a century. A large number of resource analyses have focused on the initial stages of tool production with minimal emphasis being placed on subsequent use and maintenance. This is somewhat surprising given these later stages were as influenced by raw material variability as procurement and production. Choice of material due to preference and/or availability played a fundamental role in all stages of its use (cf. Greiser and Sheets, 1979; McDevitt, 1994). Research on post-production lithic technology is thus equally relevant to fully understanding the processes of raw material acquisition and use.

One of the recurring themes of this dissertation is inclusiveness in terms of the need for lithic analysts to consider the entire life histories of stone tools, not just their initial manufacture. With this in mind the following is a brief overview of archaeological lithic resource studies, their strengths and their current limitations.

Chipped Stone Tool Resource Studies: An Overview

Lithic Properties and Variability

There is a general consensus amongst archaeologists that there was a preference in the prehistoric past for lithic raw material that displayed appropriate levels of both workability and functionality. Several definitions have been put forward to describe and distinguish between various types of stone used in the production of flaked tools. Referring to two of the most commonly used raw materials, Don E. Crabtree (1972) distinguished between chert and flint by describing the first as a "...fine-grained siliceous rock [or] impure variety of chalcedony resembling flint [that is] generally light colored" (ibid: 51, in brackets added), and the second as "a siliceous material ideally suited for flaked implement manufacture [and] usually a fine-grained rock of the darker shades." (ibid: 65, in brackets added)

Clearly these definitions do not encompass the full range of variation in prehistorically used raw material, much less help in differentiating between them. John Emery Adams (1976) offered a somewhat more comprehensive definition of both chert and flint:

> "Chert or flint is a hard, tough, fine-grained siliceous rock frequently used by early men for tools. The two names are used almost interchangeably for rocks of the opal, chalcedony, chert-flint, quartz groups. Minerals of this group are composed dominantly of silica or silicon dioxide. Members of the group are differentiated on the basis of decreasing water content and increasing crystal size." (ibid: 6)

Although Adams' definition covers a greater range of physical variability in lithic raw material there are other characteristics that could be incorporated into such a definition. The significance of conchoidal fracture, for example, cannot be overstated since it permits the degree of control necessary for effective chipped stone tool manufacture.

The variability of these definitions is matched by the number of methods used to distinguish between different varieties of lithic raw material. Characteristics including colour, texture, grain-size, the presence or absence of inclusions, mottling, lustre, and patina, have frequently served, in several different combinations, as a basis for categorizing different types of stone used in the production of prehistoric toolkits.

David J. Ives (1985) pointed out the lack of methodological rigour that seems to characterize the majority of resource studies in this regard. He cites the insufficient use of related databases, in particular those from geology, as well as inadequate use of relevant information in the drawing of correlations between the materials represented in archaeological assemblages and source locations (ibid: 212-213). He lists what a basic attribute summary of a given chert sample should include:

> "...a *bare bones* (and usually inadequate) minimum, description should include: 1) the chert's color and the variability in color(s); 2) luster and texture (and any variability); and 3) fossil content and variability. These data usually are useful only for purposes of description. To be optimally useful to archaeological research, information also should be included, where appropriate, about the geological and geographical occurrence; the spatial boundaries of the source(s); the geographical/archaeological distribution; and petrographic, trace element, or other quantitative and objective characterization data." (ibid: 214, 217; emphasis original).

A few more recent studies have begun to incorporate the various elements recommended by Ives. These include Glascock, Kunselman and Wolfman (1999); Hoard, Holen, Glascock, Neff and Elam (1992); Hughes (1994); and King, Hatch and Scheetz (1997). These studies expand upon traditional methods of lithic raw material characterization by employing instrumental neutron activation analysis and x-ray fluorescence to chemically identify and distinguish particular varieties of obsidian, chalcedony and jasper. The chemical differentiation of these materials and their comparison to samples from known source locations functions as a basis for reconstructing the methods of their acquisition and in turn gives information on the nature of their use.

G. Rapp Jr. and Christopher L. Hill (1998) in assessing the techniques of geological sourcing, in particular trace-element analysis, write:

> "The rapid growth of accurate, automated techniques for trace-element analysis has made the modern development of provenance studies possible...These newer techniques can be used economically on large numbers of samples under standard conditions so that statistically valid results can be achieved." (ibid: 147)

Tim Church (1994) provides a similar review of lithic resource analyses, in conjunction with an extensive bibliography of archaeological resource studies. The potential of such research, however, goes beyond reconstructing the patterns of raw material procurement to include the effects of these patterns on assemblage production, maintenance and use.

As a case in point, Lawrence Guy Straus (1978a, 1978b, and 1980) has investigated the effects of the use of different raw material types on assemblage variability with regard to the Solutrean toolkits from Vasco-Cantabrian, Spain (1980: 68). He proposes a link between regional raw material source locations and the rates of use of each as reflected in assemblage compositions. He argues that the "... breaks in lithic raw material composition among the listed sites...corresponds to basic lithological differences among the various sectors of the northern coastal zone of Spain" (ibid: 69). He continued by suggesting that the type of raw material used also influenced other aspects of the resulting lithic assemblages. He writes: "Lithic raw material may be a factor governing tool size (due to cobble/nodule size) and manufacturing expediency (due to relative availability of materials)" (ibid: 71). These observations, while still emphasizing initial production, are indicative of the extent to which the effects of lithic raw material selection and use permeate tool life histories.

Prior to further evaluation of these effects a review of early raw material resource studies is appropriate. This, in the form of an examination of the earliest published records of quarry site excavations, will comprise the next section of this chapter.

Raw Material Procurement Investigations

The methods of raw material procurement and the preliminary processes of tool production have been documented and described since the late nineteenth century. K. Bryan (1950), R. G. Coffin (1951), G. Fowke (1892b), R. F. Heizer and A. E. Treganza (1944), W. H. Holmes (1890a, 1890b, 1891, 1894b, 1900, 1907, 1919), W. W. Jury (1949), W. A. Phillips (1900), W. Taylor (1898), and T. Wilson (1897), among others, pioneered the investigation of both general techniques of lithic quarrying and the more specific aspects of individual quarry sites across North America. Holmes has offered fairly detailed descriptions of some typical features of quarry sites in the Mississippi Valley. These features include the common arrangement of a larger circular quarry pit surrounded by a series of smaller "lodge-shops" where the primary reduction of quarried nodules most likely took place. He states:

> "The fragments and masses of fresh chert were selected and removed from the (quarry) pits and the work of reduction and manufacture begun. Shops were established on the margins of the pits, on the dump heaps, and at convenient points in the vicinity..." (Holmes, 1894b: 11; in brackets added)

He also provides a summary of the artifacts recovered from such sites. These range from the unmodified debris found around the perimeters of both the quarry pits and lodge-shops, through partially modified pieces likely discarded due to flaws in the material or mistakes on the part of the knapper, to finished implements (Holmes, 1894b: 13-18). This last group contains either the newly manufactured tools, the tools used in quarrying and reduction processes or both (ibid).

The early work of researchers like Holmes (1890a, 1919), Taylor (1898) and Wilson (1897) was therefore primarily descriptive in nature, and as a result did not take full advantage of the information represented by the assemblages they recovered. More detailed debitage analyses, for example, can offer considerable insight into how a given type of raw material was used and the various reduction techniques employed at a single site. Moving in this general direction, quarry research toward the middle of the twentieth century began to take a closer look at quarry assemblages (e.g. Bryan, 1950) by considering all components, not just prepared cores and finished tools, worthy of detailed study.

Quarry sites, however, are not the sole focus of resource studies. The exploitation of secondary or alluvial deposits has also been of interest to lithic researchers (e.g. Amick, 1980, Gatus, 1980). Jack H. Ray (1981, 1982) developed a preliminary test for both the quantity and quality of stream-deposited chert nodules. As part of his work in the Harry S. Truman Reservoir area of southwest Missouri, Ray excavated a series of 1 x 1m squares to obtain a count of flakeable nodules per unit. He also made an effort to collect samples for determining the relative quality or 'knappability' of each type of stone (1982: 6, 8). He used variables including degree of conchoidal fracture, coarseness, the presence or absence of fracture or cleavage planes and the presence or absence of inclusions, to assign quality designations to each sample (ibid: 8, *Table 1*).

Based on this research, Ray concluded that by determining the relative abundance and utility of different types of alluvially deposited cobbles of chert, one could predict prehistoric rates of secondary source exploitation (ibid: 12). Michael D. Wiant and Harold Hassen (1983, 1985), however, question Ray on two fronts. The first is that the criteria of abundance and knappability, as defined by Ray, may not reflect prehistoric selection considerations, and the second concerns the suitability of modern streams as analogs of their prehistoric counterparts (ibid, 1983: 43). These criticisms simply reinforce the need for developing increasingly rigorous methodologies to ensure the accuracy and reliability of research results.

This methodological rigor must also be applied when examining the impact of procurement strategies on post-production processes within a chipped lithic industry. Patricia A. McAnany (1988) proposed that a causal relationship likely exists between method of raw material procurement and the nature of subsequent curation and recycling practices (ibid: 6). She drew a basic distinction between *direct* and *indirect* procurement strategies to emphasize the state of raw material upon its entry into a particular use context. This is the contrast between "... the direct acquisition of lithic resources through visits to a source area, [and] the acquisition of finished tools indirectly through the mechanism of an exchange network" (ibid; in brackets added).

McAnany suggests that depending on the procurement strategy involved, the factors that determine the nature and frequency of curation and recycling will differ. Curation will be a function of the degree of logistical planning involved in a direct procurement strategy, whereas it will be a function of the nature of social relations in an indirect procurement strategy (ibid: 7). Recycling, on the other hand, will be determined by unanticipated functional requirements as part of a direct procurement strategy, whereas it will be a response to functional exhaustion of a tool as part of an indirect procurement strategy (ibid: 8).

The form in which lithic material enters into a given use context almost certainly plays a determining role in how it is subsequently employed, but is by no means the only variable at work. One such variable not taken into account by McAnany is the lithic material itself. Different varieties of chert, flint or other types of useable raw material will perform in different ways, and therefore require different approaches to their curation and/or recycling. The systematic incorporation of raw material type into the kind of analytical framework established by McAnany would significantly refine our understanding of the relationships she has begun to identify.

To date, McAnany's work remains something of an exception rather than the rule when it comes to resource studies. Gunter Smolla (1987) outlines a number of different issues raised by more traditional resource research, from the basic nature of procurement processes, to the larger economic functions they served, to patterns of resource exchange and technological innovation (ibid: 127-129). All such issues contribute to overall patterns of raw material acquisition and use. As such, to better contextualize the present study within the larger framework of an expanded conceptualization of lithic reduction a brief consideration of some models of stone tool production and distribution is in order.

Chipped Stone Tool Production and Distribution

The basics of stone tool production, and the mechanisms of their distribution across the archaeological landscape, are fundamental to understanding how tools were subsequently used and maintained over time. The tendency has been to focus on one or a few particular component(s) or stage(s) of stone tool production and use. The preliminary stages of cobble reduction, either *in situ* at a quarry or at a nearby workshop, are among the most frequently studied. Bryan (1950) offers a fairly concise summary of the *theory of the blank* as first conceived by Holmes at the turn of the last century (Bryan, 1950: 5-7). He describes Holmes' work at the quarry site at Piney Branch, Washington, D.C., (1890a) in terms of the methodology Holmes' followed in collecting his artifact samples and in subsequently formulating their interpretation. Bryan states:

> "In collecting from the mining waste [Holmes] rejected chips and also some of the cores from which chips were derived. He selected *tortoise backs* or boulders chipped in from the side so as to make one side a crested ridge. He also selected *double tortoise backs* which were boulders chipped on both sides and therefore bifaces...He postulated that these forms were a series in the production of a more or less oval blade 4 to 5 inches (11 to 13 cm) long and 1/2 to 3/4 of an inch (1 to 2 cm) thick. Each member of the series was a rejected piece, abandoned because the artisan encountered obstacles in the production of the required form." (ibid, 1950: 5, in brackets added, emphasis original)

Holmes' work represents one of the earliest interpretations of a chipped stone tool production sequence, but is also something of an oversimplification. The most obvious cause of this was his seemingly random rejection of portions of the assemblage prior to its interpretation.

Additionally, Holmes (1890a) often hinted at the inherent variability in form of quarry artifacts at various stages in the larger production process, but concluded that ultimately they all passed through the same initial reduction sequence and resulted in a common form, the bifacial blade or blank (ibid: 13, 18). He seems to have indirectly invoked the concept of equifinality as means of accounting for observed variability in lieu of recognizing the possible presence of multiple reduction sequences, and therefore multiple products, as demonstrated by the different artifacts recovered from the quarry site. Bryan (1950) recognized the broader range of functions such a quarry site could have potentially served. He states:

> "...that many of the so-called *blanks* and *rejects* are usable tools, mainly axes, and that they were actually used; [and] that many flint quarries were not only sources of flint for export, but also industrial sites or factories to which materials such as wood and bone were brought to be worked in the presence of abundant tools." (ibid: 3, in brackets added, emphasis original)

More recent studies of the patterns of initial tool stone reduction have expanded upon the idea of more complex processes governing tool production (e.g. Binford and Quimby, 1963; Crabtree, 1972; Muto, 1971a, 1971b; Tixier, 1974; Wilmsen, 1970; and Young and Bonnichsen, 1984).

Binford and Quimby (1963), in their assessment of some chipped stone industries in the northern Lake Michigan area, recognized that the multiple artifact forms they documented reflect the multiple reduction processes that took place within these industries. They stated:

> "Since tool production is a process, the techniques and motor habits of which vary stylistically and according to their relative efficiency, it should follow that variations in the processes of tool manufacture are as important to our understanding of extinct cultural systems as the variations in the tools themselves." (ibid: 277)

Binford and Quimby identified, for example, six varieties of bipolar cores implying the prehistoric use of six variants of bipolar reduction (ibid: 289).

Richard M. Gramly (1980) echoed this more complex view of chipped lithic production in his investigation of a prehistoric rhyolite quarry in northern New Hampshire. He recognized three major classes of artifacts in the assemblage recovered from a workshop associated with the quarry. They are debitage (including waste flakes), cores and unfinished tools; tools of manufacture; and curated tools (ibid: 825). The second category is composed of those tools used in the process of procuring the rhyolite, and in its initial reduction. The third category of artifacts represents the functionally exhausted tools brought to the workshop to be replaced by the newly produced implements (Gramly, 1980: 826). These three broad classes of artifacts, and the various categories within each, are indicative of the multiple processes that likely took place at or near prehistoric quarry sites, and in chipped stone tool production in general.

Robert G. Elston (1986), in an attempt to map out these processes and their various inter-relationships, conducted a structural analysis of chipped stone tool production. Following a somewhat modified form of evolutionary structuralism; he proceeded by identifying basic structural concepts as they apply to lithic technology. Elston states that:

> "A *flaked stone lithic production subsystem* is any subsystem of a socio-cultural adaptive system, the outputs of which are manufactured (passively modified) stone artifacts, or products, created through the process of lithic reduction." (ibid, 1986: 138, emphasis original)

He suggested that such subsystems were constrained by the basic mineralogical properties shared by all the commonly used raw materials (ibid: 139) and together with some fundamental reduction units, including flake scars, pockmarks and striae, provide the structural framework for stone tool production. (ibid: 147)

Elston added that the remaining structural components fall under the heading of *production units*, including blanks, flakes and cores (ibid: 148). He articulated all of these units into trajectories comprised of rules governing reduction, the types of products generated and the relations between the two (ibid: 180-182). These trajectories form a kind of lithic grammar that is designed to inform the analyst on the production history of a given assemblage. Elston's approach is limited in its applicability as it assumes a higher degree of uniformity or regularity in chipped stone tool production than is often the case. It does not account for the possibility of multiple reduction techniques being employed within the same production system under the same structural constraints, but rather views such systems as largely unilinear in their operation.

Chipped lithic production systems are, in fact, more complex than Elston's model would suggest. The production techniques discussed by Binford and Quimby (1963), and others, hint at the large degree of variability inherent in such systems. This variability has been increasingly recognized over the last decade by researchers studying the evolution of Paleolithic tools recovered from several areas of the Old World (e.g. Baumler, 1995; Boëda, 1995; Collins, 1975; Copeland, 1995; Karlin and Jolien, 1994; Lemmonier, 1986; Leroi-Gourhan, 1993; Marks and Monigal, 1995; Olivier, 1999; Ronen, 1995; Schlanger, 1990, 1994; Sellet, 1993). The concept of the *Chaine Operatoire*, or "operational chain", commonly applied in Paleolithic research allows for the realization that the decisions made by the prehistoric knapper were products of both anticipated needs and unexpected contingencies. The Middle Paleolithic Levallois reduction technique has, as a result, been recently reinterpreted as representing a more general process rather than the means of manufacturing a specific product. This greater degree of variability in stone tool production also extends to the manner(s) in which these processes articulate with the rest of prehistoric society.

Jonathon E. Ericson (1984) examined the potential of lithic production analysis as a means of not only understanding the processes involved in stone tool manufacture, but also of how they relate to the larger socio-cultural system. He stated:

> "The structure of a lithic production system will reveal a great deal about the investment of human energy involved in production and decision-making, having economic import. The nature and internal organization of these systems are important to further our understanding of production and resource utilization in the context of procurement, exchange, technology, and social organization." (Ericson, 1984: 3)

He further suggested that reconstruction of production systems could be carried out with the use of techniques originally developed for the study of exchange systems (ibid). Ericson believes that by calculating various indices, such as *Exchange*, *Debitage*, *Cortex*, *Core*, and *Biface Indices*, the analyst will be able to trace the spatial relationships represented by these indices and thereby reconstruct the nature and extent of the production system (ibid: 4).

Similar to the processes involved in tool production, those behind the distribution of partially reduced cobbles or finished tools across a given region are equally complex. Distribution of lithic raw material types across an archaeological landscape is first and foremost a function of the strategies employed in their procurement. Lewis Binford (1979), as part of his ethno-archaeological work among the Nunamiut Eskimo, documented a pattern of raw material procurement that he described as being *embedded* within a larger subsistence strategy (ibid: 259). He writes:

> "Raw materials used in the manufacture of implements are normally obtained incidentally to the execution of basic subsistence tasks. Put another way, procurement of raw materials is embedded in basic subsistence schedules. *Very rarely, and then only when things have gone wrong, does one go out into the environment for the express*

> *and exclusive purpose of obtaining raw material for tools.*" (ibid, emphasis original)

Having put forward this interpretation, Binford pointed out that an embedded strategy is likely to be strongly associated with more mobile or logistical subsistence practices, like those of the Nunamiut Eskimo (ibid: 270). The foraging strategy of more sedentary groups is therefore more likely to be characterized by direct procurement of raw materials involving the formation of specialized parties for obtaining these resources (Binford, 1979:270).

Robert A. Ricklis and Kim A. Cox (1993), however, suggest that the relationship between lithic raw material procurement and general subsistence practices is far more complex than Binford (1979) indicates. Ricklis and Cox examined the lithic technological organization of late prehistoric Texas gulf coast populations as a cultural subsystem dynamically articulated with overall subsistence and settlement behaviour. Rather than considering raw material acquisition as having been entirely dependent on general subsistence and settlement patterns they proposed that:

> "The spatial structure of lithic technological organization was the product of a logistical pattern of procurement and transport of raw materials that was not correlated to the residential mobility patterns inherent in subsistence. These two cultural subsystems were organized according to definably different principles - lithic technology was based on a strategy that compensated for increasing technological inefficiency in order that more fundamental requirements of biotic-resource procurement could be fulfilled." (Ricklis and Cox, 1993: 445)

Taking a similar tack, William Andrefsky Jr. (1994) addressed the issue of technological organization as a function of raw material availability. He examines toolkit composition in terms of the relative proportions of formal and expedient tool forms as conditioned by raw material abundance and quality (ibid: 21). He stated that his "...paper takes issue with the premise that stone-tool production can be predictably linked to prehistoric settlement configurations without first considering the availability of lithic raw materials" (ibid).

The various procurement strategies discussed by the authors mentioned above served to remove raw material from its natural context, but still they represent only part of the distribution process. The subsequent exchange of these materials between spatially disparate groups also played a primary role in the dispersal of raw material across the prehistoric landscape.

One of the most common goals set out by researchers studying the distribution of useable tool stone is the reconstruction of exchange networks to determine the nature and extent of interaction between various prehistoric populations. Beyond the nature of relations between participants in the exchange process, the physical distribution of different raw material types, and therefore their relative availability, likely had a direct impact on the form of finished tools and the subsequent use and maintenance. Robin Torrence (1986) examined the patterns of exchange in the context of prehistoric obsidian trade in the Aegean. Perhaps the most discussed distributional model is the *Law of Monotonic Decrement* (ibid: 13-16). This model, first formulated by Colin Renfrew and his associates (Dixon *et al.*, 1968; Renfrew *et al.*, 1968), simply states that with increasing distance between raw material source and occupation site, the less represented the material will be in the toolkit as a whole.

Several different versions of this model have been employed in the study of interactions between groups of people in a given region. Margerie Green (1985) conducted a study of regional interaction on Black Mesa, Arizona, as part of an ongoing collaborative research project. Using raw material source identification data collected on earlier geological surveys, as well as assemblage composition information, she carried out both cluster and factor analyses to determine the rates of use of different raw materials as a function of distance to source and availability through exchange. She then interpreted rates of use and therefore the distribution of different materials across Black Mesa, as reflecting the degree of prehistoric interaction between various parts of the Mesa. Although not without its limitations, Green's work demonstrates the potential of lithic raw material use studies as a means of asking and at least partially answering questions dealing with larger socio-cultural issues.

Another example of this is the work carried out by Susan C. Vehik (1986) on late prehistoric chipped lithic procurement practices on the Southern Plains of Oklahoma. Focusing on the exploitation of a single type of raw material, Florence-A or Kay County chert (Cooper, 1975), Vehik examined how patterns of lithic procurement and production reflect the advent of longer-range trade (Vehik, 1986: 141). She argued that with the establishment of more formal trade networks, greater emphasis was being placed on "...the reliability and predictability of resource quality" (ibid: 142). As a result, one would expect an increase in the use of unexposed or unaltered sources of chert, in other words of quarry pits, in lieu of more easily accessible outcrop or secondary sources (ibid: 143).

She further predicted that in conjunction with a greater emphasis on resource quality there was an increase in the standardization of production (ibid). The results of Vehik's analysis, though preliminary in nature and hampered by small sample sizes, seem to suggest that patterns of procurement and production did not reflect the expansion of trade alone. Regional settlement patterns also seem to have been influenced by the choices made with respect to raw material acquisition and tool production (Vehik, 1986: 152). Similar studies have been carried out dealing with Hohokam obsidian distribution and use in the American Southwest (Bayman and Shackley, 1999; Mitchell and Shackley, 1995; and Peterson, Mitchell and Shackley, 1997.) The next section will examine in greater detail lithic resource studies carried out in the southwest U.S., specifically within the state of New Mexico.

Chipped Stone Tool Resource and Production Studies: New Mexico

The southwestern United States represents one of the most extensively studied regions on the North American continent. This is at least in part due to the high visibility of prehistoric remains, particularly the architecture of the later prehistoric periods, and the fascination they inspire. The majority of research carried out in this area has been focused on ceramic analysis and the construction of culture chronologies based on ceramic data. Lithic studies, historically, have taken an interpretive back seat to the work done on pottery. The reasons for this include the small number of formal tool types from many later prehistoric sites and the perceived lack of cultural information that was thought to be retrievable from stone artifacts. It has only been within the last twenty-five to thirty years that lithic studies of any great detail have been carried out in this region.

New Mexico, Arizona, Colorado and Utah, the states that collectively form the Four Corners area of the American Southwest, have seen a considerable amount of archaeological research take place within their borders. This body of work ranges from more general commentary on lithic resource exploitation in the Southwest (e.g. Bartlett, 1935, 1942; Coffin, 1951; Dittert, 1968; Taylor, 1898), to more detailed, longer-term research into the procurement, manufacture, and use of stone tools in a particular region (e.g. Brown, 1982a/b; Cameron, 1984, 1987, 1997, 2001; Christenson, 1987a, 1987b; Green, 1984, 1985, 1986; Jacobsen, n.d.; Lekson, 1997; Leonard, Smiley, and Cameron, 1989; Love, 1997; and Parry, 1987a, 1987b).

Katharine Bartlett (1935) provided a brief overview of prehistoric mining practices in the southwest United States as they were conceived of in the first half of the twentieth century. She looked at general patterns in the exploitation of resources including turquoise, salt, and coal. In her review she discussed some of the better-known source locations for these minerals and the presumed uses to which they were ultimately put. She did not, however, delve into the minerals used in producing chipped stone tools until her 1942 paper that dealt with a tool industry from the Little Colorado Valley. In this later paper she discussed the use of an alluvial terrace as a source of secondary cobbles of quartzite and chert for the production of those implements (ibid: 36).

Alfred E. Dittert (1968) furnished lithic researchers with an account of the available resource types and locations in central and western New Mexico. His paper described what materials were used prehistorically in this area, where they could be found, and to what uses they were typically put. He also considered the distribution of these raw materials within and between archaeological collections in an attempt to ascertain any apparent patterning in their use over space and time. Dittert recognized that there are certain trends in raw material use over time in terms of material preferences, both for artifact production and resource exchange (ibid, 1968: 13).

However, his interpretations are based almost entirely on relative proportions of different raw material types within archaeological assemblages without considering how these materials were used, which is not altogether surprising given the very broad scope of his paper.

New Mexico, along with Arizona, has been one of the most intensively studied states in the American Southwest. Research done to date in New Mexico includes several regional surveys that have attempted to locate and document both natural and archaeological resources within pre-defined areas (e.g. Chapman, 1982a, 1982b; Eidenbach, 1982; Elyea, 1988; Gossett, 1982a, 1982b; O'Hara, 1988; Schutt, 1988; Warren, 1967, 1979, 1982, 1988; Wilson, 1979). It also consists of more detailed analyses of particular assemblages with the purpose of shedding light on questions dealing with the acquisition and use of lithic raw materials on a variety of scales (e.g. Bockley-Fisher, 1990; Cameron, 1984, 2001; Cameron and Sappington, 1984; Camilli, 1988; Carmichael, 1984; Findlow and Bolognese, 1984; Fitting and Stone, 1969; Higgins, 1984; Newman, 1994; Ozbun, 1987; Ross, 1973; Warren, 1974; Wiseman, 1990).

The larger-scale surveys typically cover entire river valleys or drainage basins, and attempt to incorporate most aspects of prehistoric life. A. Helene Warren (1967) provided descriptions of lithic materials recovered during the archaeological survey of the Chuska Valley and the Chaco Plateau, near the New Mexico-Arizona border (ibid: 110-134). These descriptions detail the geological properties of raw materials used in artifact production and exchange in this valley. Warren (1979) offered a similar overview for the Gallo Wash District in the Alamito Coal Lease Area, in northwestern

New Mexico. She again examined the geological deposits to assess their composition and extent of prehistoric exploitation (ibid: 14-19). John P. Wilson (1979) gave a detailed account of the Archaic, Anasazi, and Navajo occupations of the Alamito Coal Lease Area, including the composition and general spatial distribution of chipped stone tool kits (ibid: 151-292).

Warren (1982) also evaluated the mineral resources of the Lower Rio Puerco Drainage of central New Mexico (ibid: 67-75), while Cye Gossett (1982a, 1982b) examined the chipped lithic assemblages and lithic raw material types used in the Lower Rio Puerco Valley. In both of his papers Gossett analyzed the distribution patterns of both documented tool types and raw materials used in their production (1982a: 169-212; 1982b: 213-222). Adopting what he describes as an assemblage approach (1982a: 169) to analyzing tool type frequencies, he overlooked the relationships that likely existed between different implement categories according to how they changed through use and maintenance. As a result, Gossett (1982b) gave detailed consideration to both the natural and archaeological distribution of lithic raw materials throughout the valley but offered relatively little regarding how material preferences are reflected in the types of tools that were produced and how they were used. With the same aim as Gossett, Richard C. Chapman (1982a) documented the changes in projectile technology through the various periods of occupation in this valley. He also attempted to determine relative ages for the archaeological sites recorded during the survey using lithic manufacturing debris as a temporal diagnostic (Chapman, 1982b).

Warren (1988) offered some brief commentary on the lithic resources prehistorically available in the Jarilla Mountains area of Otero County, New Mexico (ibid: 273-279). As Chapman (1982b) did for the Rio Puerco Valley, James O'Hara (1988) carried out an analysis of the projectile points from the southern end of the Tularosa Basin (ibid: 191-208), the same area discussed by Warren (1988). O'Hara examined these tools for any morphological patterning in order to "...fit the projectile points collected from Phase I of the Border Star 85 survey into known typologies and to identify possible elements of a separate local sequence" (ibid: 191). His analysis involved the digitized recording of several co-ordinate points along the entire perimeter of these implements to serve as a basis for assigning typological identifications (ibid: 192-3). This focus on two-dimensional outline morphology limited O'Hara's ability to gain a fuller understanding of how these tools changed over time as they were being used and maintained.

Jeanne A. Schutt (1988) conducted an analysis of the formal lithic tools collected during the Border Star 85 survey (ibid: 209-229). Her study was "...designed primarily to maximize information about tool function and to determine whether formal tools represent the results of manufacturing activities or the results of tool use" (ibid: 209). Using macroscopic evidence of use, Schutt assigned each implement to one of three general categories, "...non-projectile point bifaces, unifaces, and marginally retouched artifacts" (ibid). Following this, she performed more detailed quantitative analyses to make the final tool type identifications. Although Schutt does incorporate a number of different data sets generated by independent analytical techniques, her results do not reflect the full extent of variability exhibited by the tools in terms of how they changed through manufacture, use and repair. In a more traditional vein, Janette M. Elyea (1988) analyzed the lithic assemblage from a Paleo-Indian occupation recorded during the same survey. Her paper presented a straightforward morphological analysis with the goal of assessing both intra- and inter-site variability in order to place this occupation within its regional context.

These regional survey projects are relatively few in number, but offer a great deal in terms of the wide range of data they generate. Although many aspects of prehistoric life are investigated during the course of such survey projects, the resulting reports are typically less in depth than those produced by very goal specific resource studies (e.g. Bockley-Fisher, 1990; Cameron, 1984, 2001; Cameron and Sappington, 1984; Camilli, 1988; Carmichael, 1984; Fitting and Stone, 1969; Higgins, 1984; Newman, 1994; Ozbun, 1987; Ross, 1973; Warren, 1974; Wiseman, 1990). The following studies were carried out with specific questions about raw material acquisition, distribution and use, in mind. The scale at which these projects have typically been run ranges from a single occupation or quarry site to a number of sites and often a combination of the two.

James E. Fitting and Lyle M. Stone (1969) examined the distribution of raw materials among three Mimbres village sites in the Cedar Mountains of southwestern New Mexico. They focused on two quarries as the source of the raw materials under consideration. They state that:

> "Factors of site function, differential selection of raw materials for different tool types and the knapping characteristics of these raw materials had to be studied before the finished tool weight was demonstrated to be the key selective factor." (ibid: 207)

They found that at two of the three village sites, which are located equidistant between both quarries, the rate of use of Pauley Jasper, the less workable material, was higher than that of the finer Pauley Chert (ibid: 211). Fitting and Stone found that the weights of both unmodified flakes and finished tools of Pauley Jasper are considerably less than for those of Pauley Chert (ibid). They suggest that the lighter weights may be a result of either distance of transport, or of the fact that Pauley Jasper produced more tools per pound of material than did the chert (ibid: 212). They further suggest that the second alternative is the more effective at explaining the prehistoric preference for the lower quality material. Fitting and Stone did not, however, give any consideration to how the tools made from each raw material were used in post-production contexts at the village sites. Increased insight into the nature and intensity of their use would raise the possibility that the preference for Pauley Jasper may have been the result of higher intensity of use of the resulting tools, thus generating a higher rate of production of replacement implements. If this is indeed the case, wear patterns on these tools would be a particularly relevant source of information as the simple identification of function would be insufficient given the use of both materials in the production of a similar range of tool forms.

Jack A. Ross (1973), during the excavation of the Macho Draw chert quarry in Chaves County, New Mexico, documented not only the quarry itself but the associated workshop or primary reduction sites as well. He offers a fairly detailed account of the nature of these sites and a preliminary description of the assemblages recovered (ibid: 27). Ross writes:

> "Two parts of this study yet to be accomplished are: (1) the excavation of a quarry-sized hole in the ridge utilizing only the tools and methods available to

> prehistoric man in order to obtain man hours per cubic foot figure and for comparative purposes with the prehistorically dug pit; (2) the spectroscopic comparison of chert ... in order to determine the potential for identification of the chert and chert sources." (ibid: 31)

Although both of these proposals are certainly worthwhile avenues of investigation, like most resource studies the focus of research does not seem to extend beyond the earliest stages of prehistoric chipped lithic production. The scope of inquiry of such resource studies must include a consideration of what happens to the tools once they leave the vicinity of the quarry site. A. Helene Warren, in addition to her work on a number of larger regional survey projects discussed above, has conducted more site-specific research as well. She examined the chipped lithic industries of Cerro Pedernal, Rio Arriba County, New Mexico (Warren, 1974), by documenting the location, form and use of quarry and workshop sites, along with providing a detailed account of the associated assemblages associated. She offers little more than basic descriptions and concludes her report by suggesting that with further research the full extent of use of the lithic materials involved can be determined, but says nothing about what form this research should take. Here again, the focus of investigation is on the initial stages of tool manufacture and use rather than on the entire manufacture and use-life spectrum.

Catherine M. Cameron (1984) adopted a regional perspective in her assessment of lithic raw material use in Chaco Canyon, New Mexico. She first examined the use of different types of raw material as a function of distance to source. She then looked at the variability of tool stone consumption through successive 100-year periods ranging from AD 920 to AD 1220 and between different site types, specifically towns and villages. The principal aim of Cameron's study was to further clarify the role of Chaco Canyon in the regional exchange system (ibid: 150). She found significant temporal variation in the use of exotic tool stone (e.g. Washington Pass Chert), but did not find any evidence suggesting differential use of this or other types of stone, either over time or between towns and villages (ibid). Her analysis, however, was limited to the acquisition and primary reduction of material and its initial distribution across the archaeological landscape. She did not discuss how the raw material and/or finished tools were used once they arrived at the various towns and villages excavated in the canyon.

Howard C. Higgins (1984) wrote about the lithic raw material sources of the Ancho Canyon area, York Canyon region, New Mexico. He provided information on the geological history and distribution of prehistorically used sources of stone, but this is as far as he went with his investigation. David L. Carmichael (1984) studied lithic procurement practices near Clayton, New Mexico. Three procurement sites were identified and tested as part of a survey commissioned prior to the installation of powerlines transecting these sites (ibid: 171). Through comparisons of raw material types, finished tool frequencies, percentage of dorsal cortex on flakes and dorsal flake scar types between the three sites, Carmichael concluded the following:

> "The results of this study suggest there were at least two lithic procurement strategies in operation in the Tromperos drainage during prehistoric times. One involved material selection, initial core reduction, and probably the manufacture of bifacial core/blanks. The second strategy consisted of the reduction of local gravels into expedient tools." (ibid: 182)

One of questions left unanswered, according to Higgins, is whether both of these were part of the same overall subsistence strategy or represent separate subsistence practices. This is in part due to a lack of temporal control cited by Higgins as a limiting factor for all archaeological research done in this area (ibid: 182). Along with a more detailed chronology, analysis of how the raw material was employed in the context of more permanent residence sites would also go a long way to resolving this question.

Terry Lee Ozbun (1987) conducted his Masters thesis research on the Buttonhole rockshelter/quarry site in northeastern New Mexico. Ozbun included an experimental component in his analysis in order to reconstruct the reduction sequences represented by the assemblage so they can serve as a basis for inferring site function within the context of a larger subsistence system (ibid: 124-125). Through detailed examination of both finished tools and production debitage he was able to identify two reduction strategies associated with the available raw material. He states:

> "The first [strategy] primarily involves flake core reduction of blocky orthoquartzite materials procured from a bedrock source at the site. The second strategy includes heat treatment of chert pebbles and bipolar splitting of the most rounded pebbles." (ibid: 126; in brackets added)

He further notes that generally the same types of tools were produced through both reduction strategies, but that mudstone seems to have been the preferred material for the production of projectile points and orthoquartzite for larger bifacial tools (ibid: 127). Although Ozbun restricted his analysis to the Buttonhole rockshelter/quarry site, and therefore to the types of artifacts and activities associated with a chipped lithic acquisition and production locale, he does recognize the anticipatory nature of the technology. He writes: "Export of orthoquartzite flake blanks from the site indicates that site inhabitants apparently anticipated further reduction and use of the orthoquartzite materials in other places and at later times" (ibid). The goal of Ozbun's thesis, as he clearly states at the outset (ibid: iv), is to reconstruct the activities at this site and the purpose behind them in regard to the larger subsistence strategy. However, his thesis also helps to establish the idea that once tools are produced and removed from their site of manufacture, they continue to undergo alteration through use and maintenance. If indeed, as Ozbun suggests, the prehistoric knappers did anticipate the future offsite use and renewal of the tools they produced, then it is reasonable to infer that such knowledge was in some fashion incorporated into the processes of initial production. It is therefore possible that different types of raw material, beyond the constraints of availability, were preferentially chosen for the manufacture of different tool types given the anticipated nature of their use.

Looking at the selection and use of raw material in the desert basins of south central New Mexico, Eileen L. Camilli (1988) examined the impact of resource scarcity on both the tactics of production and maintenance. She investigated the trends in raw material use through time using the framework of projectile point chronologies (ibid: 152-153). Camilli suggests that the patterns in raw material use over time may indicate that the traditional relationship between material selection and sedentism, suggesting that with decreased mobility came an increase in the use of locally available stone, may not hold true in this instance (ibid: 159). The relative scarcity of raw material in this desert basin seems to have had a significant impact on both production and use of the resulting tools. Camilli recognizes the important role that recycling played in the local lithic industry. She writes, "Given these findings, an important line of investigation would be to develop methods that gauge the degree to which recycled lithic materials occur in deposits that have been differentially exposed, and therefore differentially used" (ibid). Clearly this proposed approach could be extended to the examination of all aspects of post-production tool use to further assess the impact of raw material availability, and more generally of raw material selection, on assemblage formation.

Gail Marie Bockley-Fisher (1990) and Regge N. Wiseman (1990) examined the distribution of lithic raw materials, and patterns in their selection, across the Galisteo Basin and Santa Fe District of New Mexico in late prehistoric and early proto-historic times. Both studies were carried out with the goal of shedding some light on the nature of interaction between populations within each area as reflected in patterns of raw material use. Wiseman's analysis of both projectile points and the debris generated by their manufacture revealed that there was a tendency towards the use of obsidian in their production (ibid: 349). He also offered some preliminary suggestions as to the sources of the obsidian and other materials used. Wiseman examined points from seven different sites, but says nothing about how their use and/or rates of rejuvenation may reflect patterns of raw material selection.

Bockley-Fisher (1990) conducted a considerably more in-depth analysis of chipped lithic assemblages from six proto-historic pueblos in the Galisteo Basin, northern New Mexico, in an attempt to answer questions similar to those raised by Wiseman. The distribution of raw material types, reduction stages, and artifact size and weight were determined as a way of gauging the nature and frequency of interaction between these sites (ibid: 75-91). However, she claims that a consideration of how the tools were used, as a factor in the production of the resulting distributions, would be haphazard at best. This is due to the documented use of the land surrounding each of the pueblos to graze cattle that has almost certainly obscured any traces of use on artifact surfaces (ibid: 88). This raises questions about the number and condition of the implements recovered from within the pueblo walls relative to those recovered from the surrounding land. No information is provided regarding artifact provenience beyond that of site. This, coupled with the fact that Bockley-Fisher examined the tools for traces of wear only under low-power magnification (10x) (ibid), suggests that she may have underestimated the potential contribution of use-wear analysis in achieving her research goals. She states in her summary:

> "...that there is very little homogeneity between lithic assemblages among sites in the Galisteo Basin. Resource procurement areas utilized by each pueblo were distinct, yet overlapping, and procurement strategies differed between and within pueblos. Resource procurement areas may have been accessible to all, but were certainly not used comparably by the inhabitants at all sites." (ibid: 107-108)

A clearer understanding of these differences may be possible by considering how the tools at each pueblo were used, and how this may have acted as a potentially significant factor in raw material selection. This can likely be accomplished through more detailed use-wear analyses involving careful sampling techniques and high-power microscopy (e.g. Dumont, 1982; Greiser and Sheets, 1979; Keeley, 1980; Kimball et al, 1995; Stemp and Stemp, 2003; Vaughan, 1985).

Jay R. Newman (1994) made direct comparisons between flake dimensions and raw material source distance for the materials used at Pot Creek Pueblo and the Cerrita pithouse site in the northern Rio Grande Valley, New Mexico. He states:

> "The general decrease in flake dimensions with increasing source distance most likely reflects smaller lithic parent material sizes with increasing source distance, and a lithic technology oriented toward greater material conservation and less technological variability as the distance to the respective material source increases." (ibid: 499)

The obvious, and reasonable, implication of Newman's results is the central role that transportability seems to have played in the acquisition of the lithic raw material used at these sites. What Newman does not consider is how the use of the tools at these sites affected their dimensions between the stages of initial production and final deposition into the archaeological record. Such information would shed further light on the nature of the relationship between reduction strategies, both prior to and following entry into a residential context, and raw material source distance.

As a final case, in terms of the work that has been done in New Mexico, Cameron (2001) has published the results of her work in Chaco Canyon dealing with the role of chipped lithics in a larger regional system of interaction. The focus of Cameron's paper is on the ritualistic use of lithics, in particular projectile points, throughout the canyon. Her analysis seems to suggest the use of stone implements in ritual activities such as feasts associated with periodic gatherings, as well as in the production of ornaments (ibid: 91). The inferences she does make regarding use (ibid: 91-92) are based on examinations she conducted of tool edges under low-power magnification. Cameron fully recognizes the need to carry out more detailed studies of tool use, particularly under high-power magnification. This would likely contribute to a better understanding of how the implements were used and thus of raw material use as it relates to the regional role of the canyon (ibid: 92).

There are a number of common elements that can be recognized in all the analyses discussed in this chapter. The first, and perhaps most obvious, is the central role assigned to the degree of raw material availability in explaining patterns of tool stone use in prehistory. Several factors have been identified as influencing material availability including population mobility (e.g. Bamforth, 1990; Beck and Jones, 1990; Camilli, 1988), development of exchange networks (e.g. Binford, 1979; Ericson, 1984; Green, 1985; McAnany, 1988; Smolla, 1987; Torrence, 1986) and different procurement strategies (e.g. Binford, 1979; Bockley-Fisher, 1990; Brown, 1991;

Leonard *et al.*, 1989; McAnany, 1988). However, what is conspicuously absent from these studies is any systematic consideration of how anticipated use of the resulting implements influenced decisions made regarding the types of stone used in the production of different tool categories.

There is one avenue of investigation in particular that has demonstrated a good deal of potential for shedding light on the process of raw material selection as it relates to planned tool production and use. This involves the development of techniques for the systematic identification of raw material type and source location based on its inherent mineralogical properties (e.g. Crabtree, 1972; Eley and Von Bitter, 1989; Elston, 1986; Green, 1984; Ingham and Dunikowska-Koniuszy, 1965; Janusas, 1984; Parkins, 1977; Warren, 1967, 1974, 1979, 1982, 1988). Still needed are detailed analyses of the production and use of stone tools as a function of raw material type in order to more fully appreciate the significance of mineralogical properties in the selection of raw materials. This line of inquiry may also add insight into the processes that generate observed variability in the production of chipped stone implements. Several authors spanning the entire history of archaeological resource studies (e.g. Barnhart, 1992; Bryan, 1950; Holmes, 1890a, 1894) have, to varying degrees, commented on the range of variation exhibited by the assemblages they studied. A better understanding of the relationship between the natural properties of a material and the manner of its subsequent use would undoubtedly provide a means of accounting for at least some of this observed variability.

Another common trait of lithic resource studies is a focus on the earlier stages of stone tool manufacture to the almost complete exclusion of the later stages of tool reduction. The major emphasis of these studies has been on quarry and workshop sites (e.g. Bamforth, 1992; Bloomer, 1991; Bryan, 1950; Coffin, 1951; Fowke, 1892b; Heizer and Treganza, 1944; Holmes, 1890b, 1894; Jury, 1949; Phillips, 1900; Taylor, 1898; Wilke and Schroth, 1989; Wilson, 1897) and/or the movement of procured lithic raw material across the prehistoric landscape (e.g. Binford, 1979; Ericson, 1984; Green, 1985). This focus on the initial production stages of lithic technology can also be said to characterize the majority of *chaines operatoires* and related forms of lithic research that are currently being conducted in Europe and elsewhere in the Old World (e.g. Baumler, 1995; Boeda, 1995; Collins, 1975; Copeland, 1995; Karlin and Jolien, 1994; Lemmonier, 1986; Leroi-Gourhan, 1993; Marks and Monigal, 1995; Olivier, 1999; Ronen, 1995; Schlanger, 1990, 1994; Sellet, 1993.) The expansion of traditional resource studies to include an examination of how the tools were used in residential contexts is necessary in order to understand the full range of considerations that likely went into the process of selecting raw material for the production of stone tools.

The potential of use-wear analysis in furthering this type of research has been largely unrealized and therefore under-represented in the current literature. The detailed examination of tool edges and surfaces can offer a great deal of insight into how raw material selection relates to tool use, especially in a more permanent residential context. The type of stone used may be associated not only with the kind of tool produced, and therefore with its primary function, but also with the intensity and variability of its use over the course of the tool's entire use-life. Use-wear analyses would also be particularly informative when dealing with archaeological assemblages composed primarily of expediently utilized flakes, which is typically the case on

Puebloan sites in the American Southwest. The low number of formal tool types described by several southwest researchers (e.g. Barnhart, 1992; Brown, 1982a/b; Green, 1985) need not be a limiting factor in assessing the relationship between raw material selection and later tool use. Use-wear studies can serve to increase the potential of utilized flakes for shedding light on patterns of tool use.

As a final point, most lithic resource studies share a lack of emphasis on experimental work as a means of more precisely gauging the nature of tool manufacture and use as a function of tool stone type. A few researchers (e.g. Bloomer, 1991; Brown, 1982a/b) have discussed the potential of such investigations, but there has been no extensive implementation of this approach to resource studies. One could take experimentally produced implements and use them in a traditional manner to assess both the nature of use-wear production and accumulation, as well as the frequency of required maintenance as a function of the raw materials being used.

The various strengths and weaknesses of the lithic resource studies discussed above are not mutually exclusive. They are very much inter-related and signify the complexity of lithic industries as wholes. It is for this reason that any investigation of the patterns of raw material acquisition must include assessments of all stages of tool manufacture and use if anything approximating a more complete understanding of these industries is to be achieved.

CHAPTER 4: RESEARCH DESIGN

With the review of Southwestern lithic studies provided in the last two chapters, two-thirds of the necessary background is now in place. To complete the contextualization of the present study and thus construction of the foundation for the research design described below, an overview of lithic experimentation and the role it has played in the history of lithic research will be given prior to detailed description of the current experimental program.

Lithic Experimentation in Archaeology

Middle-range theory has become a standard approach to archaeological inquiry (e.g. Binford, 1968b, 1981b, 1982b; Watson, *et al.*, 1971; Goodyear *et al.*, 1978; Trigger, 1989), employing bridging arguments to forge connections between prehistoric material culture and the processes that produced it. Various forms of analogy are used to generate answers for the many questions prehistoric remains typically raise. Ethnographic analogy and ethnoarchaeology have been very successful in supplying plausible explanations of processes represented in the archaeological record (Ascher, 1961a). However, with the rapid spread of modern technology this approach is becoming increasingly untenable, at least in its traditional form (e.g. Binford, 1967a; Yellen, 1977; Gould, 1978 ed., 1980). Although these studies continue to be carried out, albeit in a variety of different forms, other approaches to middle-range argument have come increasingly to the forefront of archaeological research.

The study of prehistoric remains through experimental replication ranks among the earliest analytical tacks taken by archaeologists. As early as the nineteenth century, researchers employed replicative techniques to assess the function of materials recovered from archaeological sites, as well as the purpose of the sites themselves. This history has produced a wide array of approaches to experimentation and numerous descriptions of the relation between experimental and archaeological material. Several general reviews of archaeological experimentation have already been published; some dealing with theory and range of application (e.g. Ascher, 1961b; Coles, 1967, 1973, 1979; Flenniken, 1984; Amick, Mauldin, and Binford, 1989), and others focusing on a particular area of experimental research (e.g. Proudfoot, 1965, 1967; Hester and Heizer, 1973; Johnson, 1978).

In his essay on the logic or reasoning behind archaeological experimentation, Robert Ascher (1961b) wrote:

> "The execution of an imitative experiment involves simulating in the present time that which is believed to have happened in the past in order to test the reasonableness of that belief." (ibid, 1961: 795)

Thus the potential of experiments lies in providing a means to attempt the re-creation of certain past behaviours and their limitations in that what is being tested are beliefs or assumptions, not objective facts, about the past. V. B. Proudfoot (1965, 1967) explored the comparative approach to archaeological research through an examination of experimental studies conducted throughout England and the European continent. He wrote:

> "Experiments can suggest to us the scope of the problems tackled and solved in earlier times. They can help to interpret the sites, which are excavated and the finds which are recovered. However, they cannot re-create those prehistoric communities which fashioned the materials which the archaeologist studies. Therein lies their limitation." (ibid, 1965: 132)

John Coles (1967, 1973, 1979) provided a slightly more recent overview of the experimental method, further emphasizing both the promise and limits of this approach. He stated:

> "The failure of a piece of equipment to perform an essential task is probably a good measure of its past failure if used in the same way, but the same stamp of certainty cannot be applied to the reverse; the success of a test can only show a possibility...that an artifact did in fact perform the same function in the past." (Coles, 1973: 168)

To illustrate the range of roles experiments can play in archaeological analysis Coles examined research that had been done on several aspects of prehistoric lifeways, including food production, larger-scale construction, and smaller-scale technologies. Since the publication of Coles' volume, archaeological experiments have continued to expand in both scope and application, furthering our understanding of past behaviours.

J. Jeffrey Flenniken (1984), looking at how flintknapping had been conceptualized within anthropology, distinguished between flintknappers and replicators based on their respective goals. He defined the production of "...potentially effective flaked stone tools..." as the goal of flintknappers, and the generation of anthropological data as the aim of the replicator (ibid: 188). He further argued that the recognition of finite cultural types, and their compilation into typologies, had distracted archaeologists from the dynamic process of tool production and use. He suggested that replication must be directed toward the entire reduction process and not restricted to the end product recoverable through excavation alone. He wrote:

> "Every anthropologist realizes that cultures are dynamic. Study of these dynamics is possible only through the careful collection and analysis of all stages in the lithic reduction sequence - not merely the finished, morphologically 'classic' tools or end products. This is the only way to *explain* variation." (Flenniken, 1984: 192; emphasis original)

It is worth noting that Flenniken incorporated use and maintenance as part and parcel of the manufacturing process rather than as separate post-production stages in their own right (ibid: 197). The respective reduction strategies involved in production and use are necessarily tailored to their respective aims, thus need to be considered as distinct stages within shared reduction continua.

Echoing the methodological concerns of others (e.g. Ascher, 1961b; Proudfoot, 1965, 1967; Coles, 1967, 1973, 1979) Amick, Mauldin, and Binford (1989) write, "comparison of experimental and archaeological data may result in a better understanding of the *behaviour* of *variables* useful for interpreting the archaeological record" (ibid: 1; emphasis added). As a guide to experimental research design they list the following as necessary elements in maximizing the validity of any lithic experiment: control of certain variables relative to others, precision and accuracy in measurement and broad-based applicability of results (ibid: 2-5). However, they caution that experimentation, as with all areas of lithic research, must also confront the issues of ambiguity and equifinality. As a first step in addressing these problems they concur with Flenniken's proposal that the full spectrum of variability or the full range of "...flexibility within lithic production systems..." (Amick, Mauldin, and Binford, 1989: 7), must be considered as part of any lithic experiment in order to evaluate, based on the physical evidence, the relative likelihood of one interpretation over another.

While Thomas R. Hester and Robert F. Heizer's (1973) extensive bibliography on lithic technology, experimentation and petrography serves to illustrate certain trends in replicative research, in particular the prevalence of *morphologist* (cf. Flenniken, 1984) approaches to lithic analysis, L. Lewis Johnson (1978) provided the most recent large-scale historical review of chipped lithic experimentation. Beginning by citing Sven Nilsson (1868) as the"...first scientist to use his own knapping experience to help explain prehistory" (ibid: 337), Johnson organized her discussion chronologically, providing descriptions of prevailing trends in experimentation and noting how each contributed to those that followed. Overall, she identified three basic analytical trends in this field: 1) distinguishing between natural and human agency, 2) studying prehistoric manufacturing and 3) exploring fracture patterns of fine-grained siliceous materials (ibid: 358).

Although there is little doubt that these trends are indeed recognizable in the literature, they are inter-connected, both epistemologically and methodologically, in complicated ways. It is these complexities that have to be kept in mind when designing any experimental research program.

Flake Production and Tool Manufacture

The preliminary steps taken in reducing a stone nodule to produce flakes have been examined experimentally almost since tools began to be studied in general. These studies have considered a wide array of both natural properties and methodological variables to assess how they influence, either individually or in combination, raw material reduction to ultimately produce desired tool forms. The debate that originally inspired interest in the nature of flake production centered on the differences between flakes produced by human as opposed to natural agency, ultimately addressing the feasibility of identifying as man-made certain lithic pieces, or *eoliths*, that were thought to predate artifacts previously accepted as the earliest products of human hands (e.g.

Evans, 1860; Cushing, 1879; Sellers, 1886; Holmes, 1892a, 1892c, 1893a; Warren, 1905, 1913, 1914; Moir 1912, 1914, 1919).

This debate involved many early twentieth century researchers including: MacCurdy, (1905), F. N. Haward (1912, 1913, 1921), Engerrand (1912, 1913), Abbott (1914), Lankester (1912), Schwartz (1914), and Barnes (1939). One of the more definitive *eolith* studies is Wen Chung Pei's (1936) examination of the quartz implements found at Choukoutien Cave, near Beijing, China. He cautioned against placing too much interpretative weight on the results of traditional flake production experiments because of their inability to simulate appropriate time depth and complexity of variable interactions (ibid: 352).

Apart from the *eolith* debate, experiments were also employed at this time in studies of early manufacturing techniques (e.g. Warren, 1924; Schleicher, 1927; Coutier, 1929; Pond, 1930; Barnes, 1932; Barbieri, 1937). This interest in production technologies was not new as researchers, such as Holmes (1890, 1891, 1894, 1900), Fowke (1891, 1892), and Wilson (1891, 1895, 1898, 1899) previously investigated stone tool production in varying levels of detail. An impressive example is Howard Holmes Ellis' study of Amerindian stone tool production techniques, first published in 1940 and reprinted in 1965. He followed an overview of previous work with his own experimental evaluations of the relative efficiency of different production techniques in achieving desired results. Ellis' aim in conducting this study was not only to refine our understanding of prehistoric flint knapping techniques, but also to educate the general public about these early technologies. Thus restriction of analytical focus to a single segment of the entire reduction spectrum was a very early and very persistent phenomenon in lithic research.

Through the mid-twentieth century this narrow focus continued to typify a growing number of experimental lithic analyses (e.g. Knowles, 1944; Neill, 1952; Bordes, 1955, 1961a, 1969a, 1970; Healy, 1962; Honea, 1965a, 1965b; Painter, 1965, 1972; Sollberger, 1969, 1970, 1971, 1976; Newcomer, 1975; Callahan, 1976a, 1979). Don E. Crabtree (1966, 1967a, 1967b, 1969, 1970, 1972, 1975, 1977; Crabtree and Butler, 1964; Crabtree and Davis, 1968; Crabtree and Swanson, 1968; Crabtree and Gould, 1970; Bordes and Crabtree, 1969) was a prolific contributor to experimental lithic research in general, and to the study of manufacturing techniques in particular. In 1966 Crabtree offered the following description of his attempts to replicate Lindenmeier Folsom points:

> "I am left with the disquieting fact that I can replicate the Lindenmeier Folsom by the use of two techniques and the nagging thought that, at this time, I cannot discard either method...My experiments indicate that this projectile point was made by either the indirect percussion with rest method, or the pressure with clamp and anvil technique." (Crabtree, 1966: 22)

This is a classic example of equifinality in stone tool production, but his results still added significantly to our understanding of Folsom technology. He also examined various other facets of tool manufacture including the use of heat (Crabtree, 1967a) and the implements used to produce chipped stone artifacts (Crabtree, 1967b). He subsequently compiled his vast flintknapping experience into a still very useful guide for aspiring knappers and academics alike (Crabtree, 1972).

The popularity of research into flake generation at the turn of the last century was channeled into, and eventually absorbed by, the *eolith* debate. As this debate ebbed in the thirties and early forties, so did research on flint fracture as an analytical end in itself. Studies of flake generation began to re-emerge with the work of Mary Ellen Goodman (1944) who was among the first researchers to 'go back to basics' and return their attention to role of raw material variability in this process. This approach, however, did not pick up any further analytical steam in archaeological circles until the early 1970s when Speth (1972, 1974, 1975, 1981), among others, began to build on the work started by Goodman almost thirty years earlier. This delayed response to Goodman's study was, in part, due to the slow realization that other fields, such as materials analysis, could make a significant contribution to lithic research. As these fields have progressed both theoretically and methodologically, so has their influence on the study of flake production and tool manufacture. Just prior to Speth's foray into fracture studies, Fonesca, Eshelby, and Atkinson (1971), as specialists in materials theory, wrote an article on the fracture mechanics of knappable material using what they described as "...a simplified mathematical model" (ibid: 421). Their paper is a perfect example of the type of work that was being done outside of archaeology that helped to forge new directions in lithic research.

In the interim between Goodman's and Speth's studies, several volumes dealing with the general principles of lithic analysis and flintknapping were produced. Lawrence B. Bixby (1945) offered a brief introduction to the tools and techniques of knapping flint. During the following decade several other experienced knappers also published general guides to the art of flintknapping (e.g. Watson, 1950; Knowles, 1953; Leakey, 1954; Mewhinney, 1957), which paved the way for landmark works by Bordes (1968), Crabtree (1972), and Tixier (1974). There were also a few studies that examined the applicability of experiments to specific issues in lithic analysis such as typology (e.g. Bonnichsen, 1968, 1977).

During the 1970s and early 1980s, John D. Speth (1972, 1974, 1975, 1981) re-examined the flaking properties of cryptocrystalline silicates from the natural sciences perspective originally adopted by Goodman (1944). Speth (1972) carried out a detailed quantitative study of the fracture dynamics of these materials to demonstrate how an understanding of such properties can be fruitfully applied to the analysis of stone tools. Harold L. Dibble and John C. Whittaker (1981) followed Speth's lead in carrying out an examination of the relation between hard-hammer percussion and resulting flake variability. They questioned, however, the interpretative potential of Speth's physics-based approach to the study of hard-hammer percussion, citing the prehistoric knappers' inability to appreciate, on a conscious level, the intricacies of fracture mechanics (ibid: 284). They chose instead to focus their research on variables that can be observed directly and therefore potentially manipulated to achieve desired ends. The results of Dibble and Whittaker's experiments in large part support those obtained by Speth regarding the significance of exterior platform angle as a direct influence on a number of resulting flake attributes (ibid: 294-296). The one discrepancy that did arise between these studies deals with the angle of impact and, according to Dibble and Whittaker, its apparent lack of influence on most resulting flake characteristics (ibid: 295).

Harold Dibble continued his involvement in experimental lithic research by participating in another collaborative effort designed to evaluate the effects of several variables on flake production (Dibble and Pelcin, 1995). Using an experimental apparatus modeled on that used by Speth the depth, exterior angle and the thickness of the platform were each examined as they relate to the mass and velocity of the hammer in an attempt to assess whether platform or hammer attributes exert greater influence on the flaking process. Through various trials incorporating different platform attributes they found that, within the limits of their study, original flake mass is largely determined by the exterior angle and thickness of the platform (ibid: 435).

Zachary J. Davis and John J. Shea (1998) in conducting an experimental test of Dibble and Pelcin's predictor of original flake mass, found that the variables they used consistently underestimated the original mass of a given flake tool and suggested that the width of the platform be added to the roster of variables Dibble and Pelcin used in their study (Davis and Shea, 1998: 609). In response Dibble (1998) agreed that any assessment of original flake mass must recognize the complex nature of variable interactions and that the width of the platform may indeed be a relevant factor (ibid: 611), but Pelcin expressed greater skepticism about the utility of the width of the platform in predicting original flake mass (Pelcin, 1998: 620).

Michael J. Shott, Andrew P. Bradbury, Phillip J. Carr, and George H. Odell (2000) further explored the general utility and applicability of Dibble and Pelcin's (1995) approach to predicting original flake size. While ultimately siding with Pelcin regarding Davis and Shea's (1998) tests, they recommend, based on their own experimental results, that Dibble and Pelcin's original model and Pelcin's (1997a/b/c) later work be refined to broaden their applicability to different raw material types and production techniques (Shott *et al.*, 2000: 893)

Several other analysts have also investigated the nature of flint fracture and resulting flake properties. Hard-hammer percussion studies include, for example, Patterson's (1981) study of striking platform geometry, Cotterell, Kamminga, and Dickson's (1985) examination of conchoidal fracture mechanics and Cotterell and Kamminga's (1987) study of the nature of flake formation. Patten (1980) studied the effects of soft stone hammers on flake production and Hayden and Hutchings (1989) conducted experiments with antler billet soft-hammers. Ohnuma and Bergman (1982) took a more technologically inclusive approach in attempting to identify means of distinguishing between different knapping techniques based on resulting flake characteristics.

Other aspects of stone tool manufacture have also been the subject of experimental research. Beyond flake production itself, different reduction techniques have been examined through experimentation (e.g. Newcomer, 1971; Goodyear, 1974; Henry, Haynes, and Bradley, 1976; Patterson and Sollberger, 1978; Magne and Pokotylo, 1981; Patterson, 1982; Ahler and Christensen, 1983; Stahle and Dunn, 1982, 1984; Magne, 1985; Amick, Mauldin, and Tomka, 1988; Kujit, Prentiss, and Pokotylo, 1995; Dibble, 1988, 1995b, 1997; Bisson, 2001). Flenniken (1985) used experiments to study the relation between three different reduction techniques and their respective byproducts during both manufacture and use of hafted projectile points. He found that, although the points themselves changed in size and shape from completion through successive episodes of use, the waste flakes produced consistently reflected the particular reduction technique employed at various stages during the entire reduction sequence (ibid: 273).

Steven A. Tomka (1989) used experiments to determine the diagnostic value of debitage attributes in analyzing the reduction sequences of multi-directional cores, bifacial cobbles and bifacial flake cores. Mauldin and Amick (1989) examined the debitage produced by experimentally reducing bifacial cores and found that despite the presence of experimental controls, the resulting debitage remained quite variable, emphasizing the complexity of lithic reduction processes (ibid: 85). Odell (1989) had an experienced flint knapper replicate a variety of lithic artifacts including flakes off a flake core, blades from several blade cores, a large biface, a Hardin barbed point and a Snyders point (ibid: 163). He found that while there were consistent differences in the debitage produced via core and bifacial reduction, distinguishing between different stages of bifacial reduction was more difficult; recognizing temporal variability in debitage attributes proved most elusive (ibid: 183).

Stemming from work done by S. L. Kuhn (1990) on quantifying reduction on the basis of unifacial retouch invasiveness, Chris Clarkson (2002) used experimental and archaeological data to develop an index of invasiveness for both unifacial and bifacial tools. After testing the index experimentally, and applying it to archaeological material from north-central Australia, Clarkson found that this index provides a reliable way of graphically representing changes in tool form as a result of periodic maintenance and recycling, particularly the further away one gets from sources of knappable raw material (Clarkson, 2002: 74). All of these studies focused exclusively on the production side of chipped stone tool life histories. Another category of experimentation can be defined by its preoccupation with various post-production phases of these histories, in other words, on the nature of tool use and its interpretation.

Use

Compared to those focused on production, experiments geared toward reconstructing the functions of prehistoric stone tools through trace wear analysis are a relatively recent development. This is especially true for western archaeology, as up until the 1970s, inferred tool function and typological identity were assessed largely according to macroscopic aspects of tool morphology (e.g. Holmes, 1894; Bourlon, 1911; Coutier, 1929; Pei, 1936; Cheynier and Barnes, 1937; Jury, 1949; Bordes, 1952, 1961a, 1961b, 1969a, 1970; Honea, 1965a, 1965b; Painter, 1967; Crabtree, 1969; Sollberger, 1969, 1970, 1971, 1976).

In his 1957 Russian volume *Prehistoric Technology* and its 1964 English translation Sergei Semenov recognized that production techniques, manner of use and post-depositional processes all contribute to the form and condition of excavated tools. He suggested that although sources of analogical data, including experimental and ethnographic research, have yielded insights into the past, the most reliable method of determining tool function is through the detailed inspection of tools to locate and identify the physical evidence of modification and use. Semenov's book thus served as an important catalyst in the development of both trace wear studies and lithic analysis in general. Reflecting the ongoing tendency towards conceptualizations of production and use as mutually exclusive technological processes rather than related components of a common reduction spectrum, Semenov equated macroscopic properties with production and microscopic properties with use. Most lithic researchers have come to recognize that his assessment considerably oversimplifies the dynamic nature of stone tool life histories. A number of more recent studies have shown that examination of larger-scale use-related edge damage, for example, can be a fruitful avenue of inquiry (e.g. Fischer, Vemming Hansen, and Rasmussen, 1984; Odell and Cowan, 1986; Titmus and Woods, 1986; Truncer, 1990; Dockall, 1997; Shott, 2002).

Trace wear analysis has continued to grow into a distinct sub-discipline of lithic and experimental archaeology, complete with its own contentious debates. Despite continuing interest in macroscopic wear patterns, microscopic use-wear studies have come to the analytical forefront in recent years, and with this new focus came differing opinions regarding the identification and interpretation of such traces (e.g. Tringham, Cooper, Odell, Voytek, and Whitman, 1974; Odell, 1979; Odell and Odell-Vereecken, 1980; Keeley, 1980; Vaughan, 1985; Berg, 1993).

These studies have generally fallen into one of two methodological camps. The first favours the use of low-power microscopy (<50x), citing the greater reliability of microfractures as a basis for inferring nature of use (e.g. Keller, 1966; Tringham *et al.*, 1974; Brink, 1978; Odell and Odell-Vereecken, 1980; Odell, 1979, 1981a, 1990; Shen, 1999). The second camp advocates the use of high-power microscopy (>50x) and the examination of surface polishes and other micro-traces as the more promising approach to use-wear analysis (e.g. Keeley, 1980, 1982; Keeley and Newcomer, 1977; Newcomer and Keeley, 1979; Flenniken, 1981; Newcomer, Grace, and Unger-Hamilton, 1986, 1987; Plisson and Mauger, 1988; Grace, 1990; Fullagar, 1991; Coffey, 1994; Hardy, 1994; McDevitt, 1994; Kimball, Kimball, and Allen, 1995; Hardy, 1994; Kay, 1996; Kay and Solecki, 2000; Stemp and Stemp, 2001, 2003).

Ruth Tringham *et al.* (1974) carried out one of the more seminal low-power microscopy studies of use-related edge damage formation. They suggested that, by following the procedures they developed, assumptions regarding the comparability of prehistoric and contemporary perspectives of tool use are rendered moot, as evaluation of microscopic edge damage can directly inform the analyst on the specifics of tool function (ibid: 195). Their work represents a significant step forward in our ability to assess tool function and has inspired several subsequent edge damage studies (e.g. Lawrence, 1979; Tomenchuk, 1979; Odell and Odell-Vereecken, 1980; Odell, 1981a; Vaughan, 1981), including those that attempt to differentiate between cultural and natural processes of edge modification (e.g. Flenniken and Haggarty, 1979; Gifford-Gonzales, Damrosch, Damrosch, Pryor, and Thunen, 1985; Levi-Sala, 1986; Pryor, 1988; Nielson, 1991; Shea and Klenck, 1993; McBrearty, Bishop, Plummer, Dewar, and Conrad, 1998).

One of the most cited experimental use-wear studies is Lawrence H. Keeley's (1980) *Experimental Determination of Stone Tool Uses*. His study falls primarily, but not exclusively, into the high-power microscopy camp, while still recognizing both the advantages and limitations of this approach. Keeley recognized that working different materials produces identifiable wear traces while at the same time their respective characteristics are not always mutually exclusive. He also noted that their distinctiveness could be a function of use intensity, post-depositional preservation or both. Despite these potential ambiguities, Keeley maintained that characteristic wear traces such as polishes can be recognized and differentiated at higher powers of magnification and, when used in conjunction with attributes visible at lower magnification such as microfractures, can serve as a reasonable basis for inferring function.

Although Keeley broached the subject of quantifying observed differences in wear formation, citing the use of a light meter to measure polish reflected light levels in the microscopic field of view (ibid: 62-63), he did not pursue the issue. He acknowledged that quantification of wear attributes is a necessary step in the maturation of microscopic use-wear studies but offered relatively few suggestions as to how this might be accomplished (Keeley, 1980: 166-168). Around this same time the issue of quantifying use-wear garnered some additional attention through the work of Dumont (1982), Grace, Graham, and Newcomer (1985, 1987) and Grace (1989).

Patrick C. Vaughan (1985) also employed a combination of low and high-power microscopy in his experimental study of Magdalenian flints from the site of Cassegros in southwestern France. He acknowledged that traditionally recognized tool categories were each likely used in the performance of a wide range of tasks but did not consider this an insurmountable obstacle to further developing use-wear analysis as a reliable and fruitful technique for understanding the prehistoric past. He also pointed out that unretouched flakes were as widely employed as more formal tools, making them equally viable candidates for trace wear analysis (ibid, 1985: 101). Inferences regarding the inherently complex use histories of curated technologies would almost certainly benefit from the analysis of wear evidence on more expedient tools as their shorter life histories served to limit the amount of functional ambiguity often associated with their more formal counterparts. This window on the nature of wear development would equip researchers with the necessary knowledge to more thoroughly assess the dynamics of tool life histories.

The progress of modern technology has fostered the development of increasingly sophisticated forms of use-wear analysis. Building on previous work dealing with the nature of polish formation (e.g. Del Bene, 1979; Diamond, 1979; Kamminga, 1979), Richard L. K. Fullagar (1991) conducted experiments using a scanning electron microscope to examine the role silica plays in this process. He found that the amount of silica in a given plant specimen, for example, can vary from one part of the plant to another and with plant age, not to mention between specimens of the same type, thereby varying the amount of silica placed in direct contact with the tool surface and therefore its resulting effect on polish formation (Fullagar, 1991: 7).

Kimball, Kimball, and Allen (1995) examined experimentally generated polishes using an atomic force microscope, paying particular attention to differences in surface texture or roughness. Several researchers had previously used scanning electron microscopes to study use-wear traces (e.g. Keeley, 1977; Meeks, Sieveking, Tite, and Cook, 1982; Mansur-Franchomme, 1983; Unger-Hamilton, 1984; Knutsson, 1988; Fullagar, 1991), but Kimball *et al.* point out that despite an improvement in resolution offered by SEM analysis, it is still largely qualitative in nature (Kimball *et al.*, 1995: 9). They developed a means of quantifying different use polishes by measuring and plotting the roughness of their respective micro-topographies.

Stemp and Stemp (2001, 2003) approached quantifying tool surface roughness through UBM Laser Profilometry. By scanning tool surfaces and recording light reflectivity along several series of points they were able to mathematically model the tools' microtopographies at various scales (Stemp and Stemp, 2001: 82-83). They recently carried out additional research examining the process of use-related micro-polish development on a single raw material type (Stemp and Stemp, 2003). Although both methods hold promise, they remain largely untested in terms of their applicability to the archaeological record. An example of a study advancing a new analytical technique that moves beyond experimentation to include an archaeological case study is Monika Derndarsky and Goran Ocklind's (2001) research on aspects of subsurface use damage in quartz tools using a confocal laser scanning microscope and dye.

As analytical technology has become more sophisticated, it has not only enhanced interpretations of familiar attributes, but also opened new avenues of investigation previously limited or entirely inaccessible. The analysis of organic residues on tool edges and surfaces, for example, has only recently come into its own (e.g. Loy, 1983; Bahn, 1987; Gurfinkel and Franklin, 1988; Newman and Julig, 1989; Hyland, Tersak, Adovasio, and Segal, 1990; Kooyman, Newman, and Ceri, 1992; Loy and Hardy, 1992; Smith and Wilson, 1992; Cattaneo, Gelsthorpe, Phillips, and Sokal, 1993; Hardy, 1994; Fullagar, Furby, and Hardy, 1996; Tuross, Barnes, and Potts, 1996; Jahren, Toth, Schick, Clark, and Amundson, 1997; Hardy and Garufi, 1998; Barton, Torrance, and Fullagar, 1998). Recent advances in our understanding of genetics have made molecular analysis and identification of organic residues a reality, making possible the further elucidation of resource exploitation strategies and the composition of prehistoric diets.

As demonstrated by this brief overview, lithic experimentation has evolved considerably since its inception and continues to grow in interpretive potential every day. With this background in mind and an eye cast on its future potential, the next section of this chapter will detail the research design, including experimental protocols, employed in the present study.

Research Design

A truly multi-disciplinary approach has been taken in this study. In addition to archaeology, the fields of geology, mechanical engineering and materials engineering were consulted, various pieces of discipline specific analytical equipment were employed, and a number of analytical procedures adopted in the process of fulfilling the project's goals. The potential of such a diversified approach to archaeological research has only begun to be realized within the discipline. The approach employed here attempts to build on previous research to both ensure a solid foundation for the present study and to provide an effective platform for future work.

As with any program of research, this study was conducted in neither a conceptual nor intellectual vacuum. Thus, as work progressed changes in analytical strategy were made as warranted. These changes were enacted in order to maximize reliability and reproducibility of results, as well as to ensure proper experimental protocols were followed at all times. First, details regarding the original conceptualization of this study will be presented. This will be followed by a discussion of the changes that took place and what motivated them.

Given this study's theoretical perspective derives from my Master's thesis on Huron lithics from southwestern Ontario, its initial methodology drew heavily from that of its conceptual forebear. This quickly became problematic in light of the geographic shift to northern New Mexico and temporal relocation from the Late Woodland to the Late Archaic. While Huron lithic technology is a combination of both longer and shorter-term use tools, often referred to as formal and expedient tools respectively, lithics from the Late Archaic of New Mexico are, with the exception of projectile points, almost exclusively shorter-term use implements. Although this did not detract from the established theoretical perspective, it did demand methodological re-evaluation.

The variables employed in my Master's thesis to gauge degree of use-related reduction are well suited for more formal or longer-term use implements such as Huron projectile points and end scrapers. They are, however, ill equipped to deal with the greater inherent variability of shorter-term use technologies characteristic of the prehistoric southwestern United States. Initially, this seemed to be a significant methodological stumbling block since I essentially wanted to assess Late Archaic lithics from this region for patterning analogous to what I found among Late Woodland Huron stone tools, only this time focusing on the role of raw material type in their life histories.

A review of Four-Corners area raw material resource studies and lithic research in this area in general revealed certain methodological trends in terms of techniques used and the scope of their application. The specifics regarding these surveys have been detailed in Chapters Two and Three of this dissertation, thus will not be re-iterated here. It is sufficient to emphasize a general tendency towards the restriction of use-wear studies to longer-term use technologies and of resource studies to the production end of the tool life history spectrum.

Despite considerable morphological variability, the brief duration and often functionally uniform nature of shorter-term tool use offer a logical medium for improving our understanding of the underlying dynamics involved in both production and use contexts and how each contributes to lithic technological variability. Without having to concern oneself with the compounding complexities of production related equifinality and multiple episodes of variable use commonly associated with more formal or longer-term use tools, the fundamentals of tool dynamics can more readily be identified and understood. The expression *tool dynamics*, as employed here, refers to the progressive and cumulative effects of manufacture and use, spontaneous and purposeful, accrued by a given tool over the course of its entire life history.

It was decided that accepted protocols for use-wear analysis of longer-term use implements could be fruitfully applied to the material from New Mexico. Even though these tools were only used for a limited amount of time as circumstances warranted, and subsequently discarded, wear is still likely to have developed to some degree as a result of one combination of factors or another. In fact, it could be argued that their use brevity makes them better suited than their longer-term counterparts for generating inferences about use-wear generation and variability.

Thus, the initial methodological shift began to take form. Instead of trying to assess technological, and therefore socio-economic, relationships between longer-term use tools of similar form, analytical attention turned toward investigating the role of lithic raw material in use-related reduction strategies as part of an ongoing research plan to examine all of the life history stages that characterize shorter-term use implements. While this may intuitively seem like a step backwards, it is actually a logical step forward that will enable studies of reduction continua to be carried out with even greater interpretive resolution. Once this first change was made, other issues began to come to the fore. One of these concerned the functional breadth of the present study.

The goal of any experimental study is to produce reliable, replicable results. At the same time an analyst will try to ensure that he or she will generate as comprehensive a study as possible. These two ideals, however, are not always entirely compatible. Matters of time, funding, and personnel all too often place practical limitations on research programs, thus necessitating the making of hard decisions in order to meet such strict requirements. The present study was certainly not exempt from this reality. The experimental program was initially designed with functional inclusiveness foremost in mind.

To this end, experiments were meant to include the performance of a wide array subsistence related tasks. These included both fresh and dry hide-scraping, planing and cutting juniper wood and planing fresh bone and antler. These tasks clearly do not cover the full range of prehistoric subsistence activities but do constitute a reasonably representative cross-section of tool use behaviour. The one prominent exception to this claim would be butchering of meat, but this activity was omitted from the start given the well-documented ambiguity of wear traces associated with this type of task (e.g. Keeley, 1980; Levi-Sala, 1986; Tringham, *et. al.*, 1974; Vaughan, 1985), and the complex nature of use motion attributable to butchering an animal carcass. Despite this intentional omission, the preliminary experimental program still proved to be overly ambitious, particularly in light of the analytical techniques being employed. It quickly became apparent that the investigation of as wide a variety of tasks as originally envisioned for this project would require several studies to complete with a reasonable degree of analytical rigor. It was therefore decided to narrow current analytical focus to tasks associated with transverse use-motions.

Before describing the experimental program itself a few brief comments regarding their conceptual framework is necessary. Most archaeologists readily concur with the idea that we need to maximize the amount of information recoverable from artifacts in an effort to fill in, as much as possible, the numerous gaps that characterize a highly fragmentary archaeological record. Virtually all forms of archaeological research are designed with these facts in mind. In keeping with scientific method, it is common practice to first endeavour to understand the underlying principles that are thought to govern processes such as wear formation and accrual prior to any attempt at drawing inferences from archaeological specimens. It has often been suggested that to best appreciate such fundamental processes it is necessary to replicate them in isolation from any external influences. While it is certainly true that to fully comprehend a particular process all relevant variables must first be understood independently of one another, it is equally true that such knowledge on its own tells very little about what transpired in the prehistoric past to generate the patterns we observe archaeologically.

At some point during our analytical pursuits we need to apply what is learned through these culturally sterile tests to the culturally imbued archaeological record. The present study is an attempt at a compromise between analytical control and naturalistic modeling. First, the decision was made to retain the human element by having people perform the experiments rather than employing an apparatus designed to hold all but one relevant variable constant during performance of the task. While this did permit a certain degree of variability from individual to individual and use action to use action, efforts were made to maximize consistency of performance. These include maintaining a constant implement to working surface angle of 45^{0}, a constant load or amount of pressure applied during tool use (essentially enough to produce observable effects), and constant stroke rate (one per second) and length (10 to 15 cm depending on activity type). Load and stroke length were allowed to vary only as a function of the physical properties of the contact materials in question. The relative hardness of these materials dictated the amount of load or pressure required to generate surface modification and their overall size determined what ultimately constituted feasible stroke lengths. Hide-working required a lesser load than that necessary for working wood, and the hides with their larger surface areas allowed for longer stroke lengths as compared to the wood specimens used.

It may seem as if too many variables were left uncontrolled, but if experimental results are to serve to improve our understanding of the archaeological record and the past lifeways that it represents, then conditions that prevailed in the prehistoric past must be reproduced as faithfully as possible without compromising experimental integrity. Efforts must be made to perform experiments as consistently as possible, but at the same time the human element must remain present to make comparisons with the archaeological record practical and informative. This perspective thus has served as a general guideline for designing the present set of experiments.

Raw Materials

A total of four different raw material types are considered in the present study. These are: San Juan Fossiliferous Chert (SJF), Brushy Basin Chert (BB), Yellow Silicified Wood (YSW), and Morrison Undifferentiated Grey Chert (MUG). These raw material types are defined according to the A. Helene Warren Lithic Raw Material Code System (revised 1996) as follows: SJF is cream to light red with a yellow-brown cortex and circular micro-fossil inclusions, BB is green to cream with a dull to glossy luster, YSW is yellow to yellow brown in colour, and MUG is dark grey with occasional brown or tan lamellae (ibid: 1996: 3, 4, 7, 12). Among the materials made available to me through the generosity of Dr. Roger Moore, these four were selected for the differing degrees of variation they exhibit and their relative abundance in the current study area.

These materials represent something of a cross-section of geological types. SJF is a biogenic siliceous sediment whereas MUG and BB are two varieties of inorganic siliceous sediments. YSW, while the product of a process analogous to the production of biogenic silica, is distinct in that it derives from plant remains, i.e. wood, rather than microfaunal skeletal material. Biogenic cherts, like SJF (*Figure 4.1*), are the result of the accumulation and progressive compaction of pelagic or biologically rich sediments that are deposited through cyclical transport of nutrients from the sea floor to near surface waters, typically over zones of oceanic upwelling (Hesse, 1988: 172). These deposits then undergo a three-stage process of mineral alteration that transforms the original biological material into various forms of silica or quartz (ibid: 175).

Inorganic cherts, such as MUG and BB (*Figures 4.3 and 4.3*), are the products of different processes. In general, the silicification of non-siliceous materials can involve a wide variety of rock types and occur to a variety of degrees (Hesse, 1989: 253). This process of silicification typically results in the generation of one of seven different silica fabrics or textures (ibid). MUG and BB both fall into the equigranular fabric category, i.e. both have typical grain diameters of between 5 and 20 microns. They are the products of extensive silicification through direct chemical precipitation from solution in lacustrine or other marine environments (ibid). The formation of YSW (*Figure 4.4*) and silicified woods in general, while similar to that of biogenic cherts, is one of permeation or infilling rather than large-scale mineralogical replacement and is characterized by only partial silicification (ibid: 254-255). Dissolved silicon in aqueous solution, typically in surface waters, is attracted to organic molecules in vascular tissue initiating chemical bonding and silica mineralization (Leo and Barghoorn, 1976; Stein, 1982).

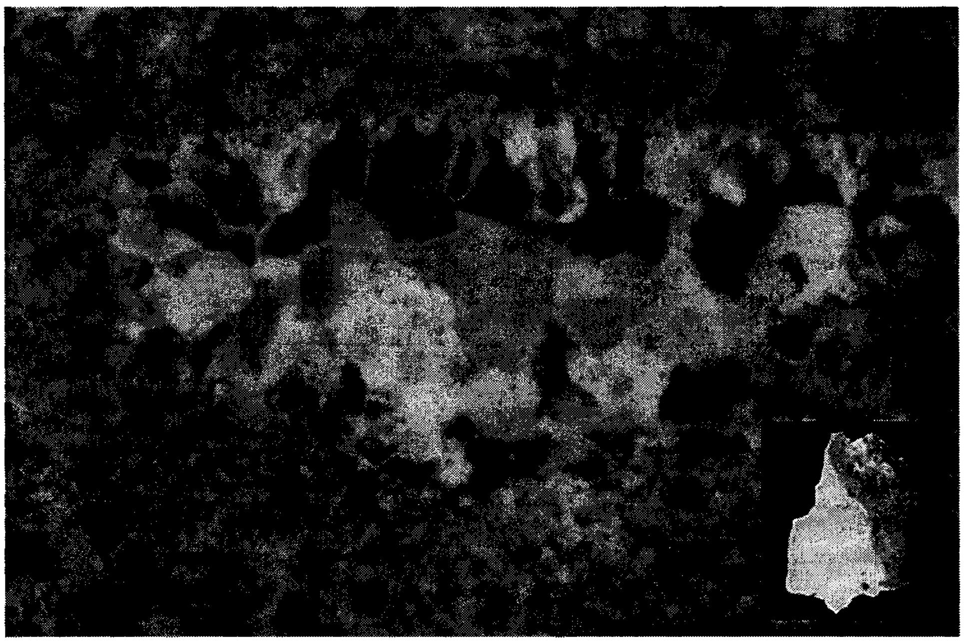


Figure 4.1: Thin section image of San Juan Fossiliferous Chert at 100x and under cross-polarized light.

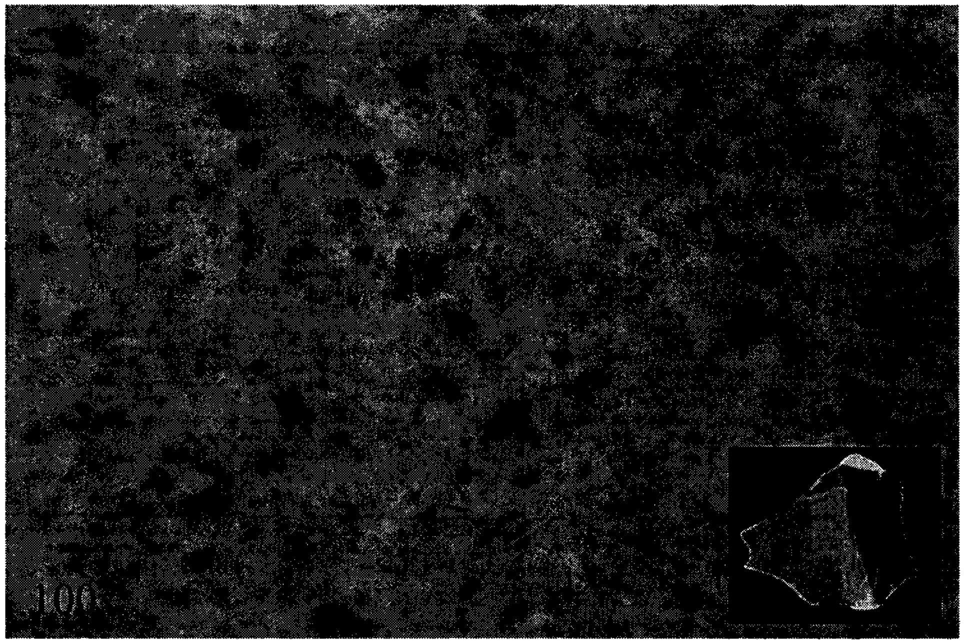


Figure 4.2: Thin section image of Brushy Basin Chert at 100x and under cross-polarized light.

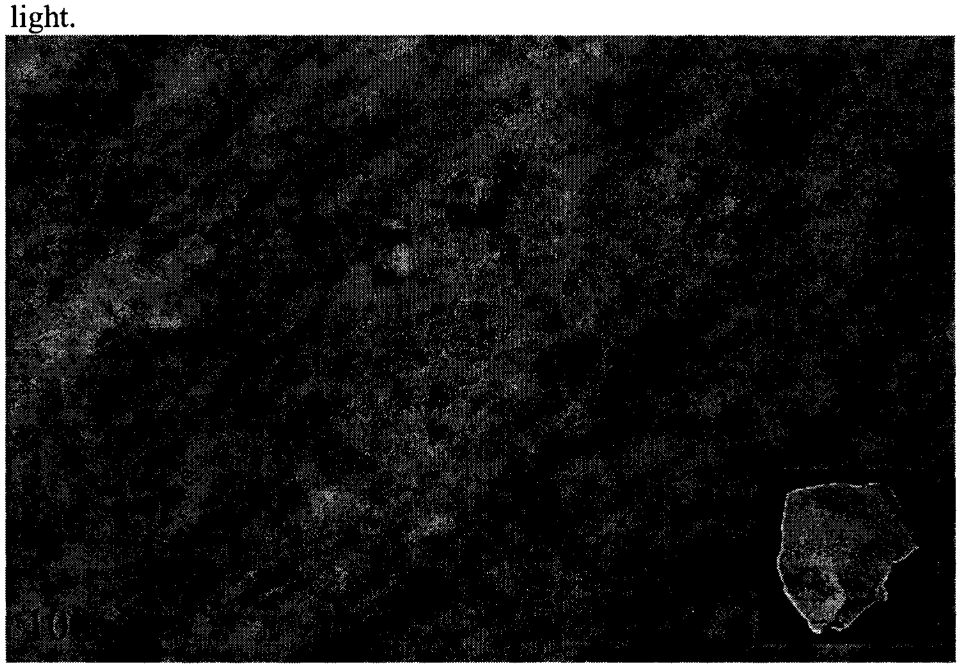


Figure 4.3: Thin section image of Morrison Undifferentiated Gray Chert at 100x and under cross-polarized light.

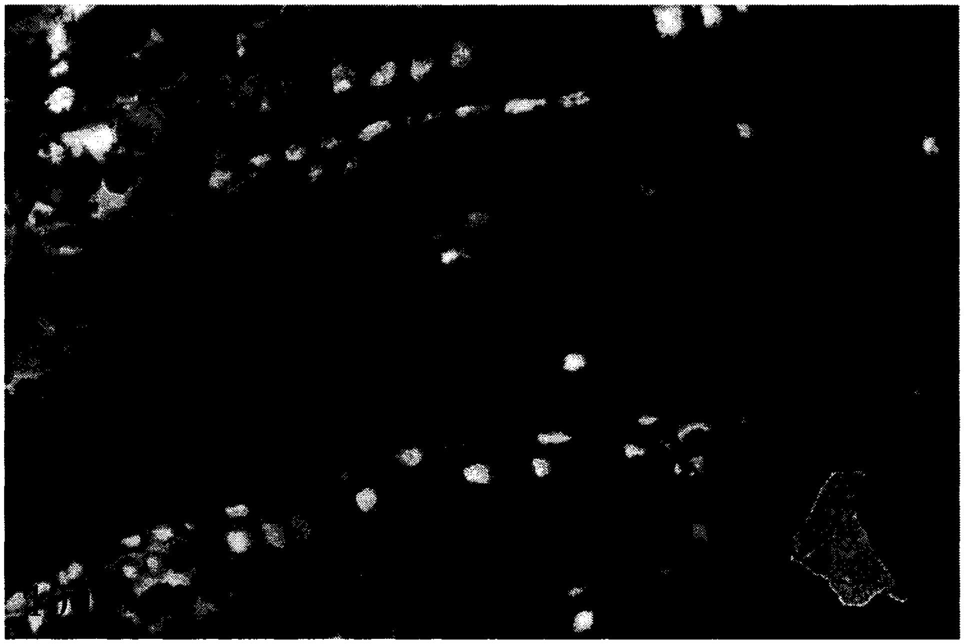


Figure 4.4: Thin section image of Yellow Silicified Wood at 100x and under cross-polarized light.

All four raw materials under consideration are available locally in the Elena Gallegos survey area near Farmington New Mexico, often occurring as secondary deposits (Schutt, 1997b). As shown on the New Mexico Geological Society's 1982 map, the geology of San Juan County area of northwestern New Mexico is comprised of deposits ranging in age from the Triassic through to the early Tertiary representing almost 250 million years of geological history. YSW may be associated with the Triassic Petrified Forest Member of the Chinle Formation and MUG and BB may derive from the Jurassic age Morrison Formation that includes the Brushy Basin Member (NMGS, 1982). SJF likely derives from Cretaceous deposits but its exact provenience remains unclear.

Although sourcing for some southwestern lithic raw materials has been carried out (e.g. Church, Caraveo, and Sirianni, 1994; Church and Hack, 1939; Geeslin and Chafetz, 1982; Hillsman, 1992; McCann, 1940; Meyers, 1977; Meyers and James, 1978), more detailed petrological analyses are needed, especially where the largely neglected silicified woods are concerned. Although the current study originally had a petrographic component, as evidenced by the thin sections obtained and depicted in Figures 4.1 to 4.4, their full analysis was not feasible as available resources permitted production of only one thin section for each material. Multiple thin sections are required to establish representative mineral compositions on a percentage basis. Petrographic analyses will, however, be part of future research I have planned.

Experimental Procedures

Prior to any experimentation, a flake of each raw material type was examined microscopically to establish a baseline for subsequent analytical reference. While no two flakes are physically identical, where possible the use of one nodule for producing all experimental flakes of a given material served to minimize within type variability. The exceptions to this rule were SJF and YSW. During reduction of the first nodule of SJF natural inclusions limited the production of usable flakes. An encounter with a natural fracture plane had the same effect on the first YSW nodule. These difficulties required the use of a second nodule in both instances. For each of these materials the two nodules derive from common source locations further minimizing, although not necessarily eliminating, within type variation. Given that no two flakes are exactly alike, it would also be useful to experimentally compare several flakes of the same raw material type, both from the same nodule and from different nodules, to assess smaller-scale within type variation. The present study's focus on larger-scale variability as it pertains to wear accrual patterns and their potential effects on tool life histories, allows for a certain degree of variability in this regard, but it should be remembered that the results presented here, like those of any study, require further testing and evaluation.

The unused flakes were scanned along the edge intended for use. The entire length of this edge was scanned at 10x magnification, and selected portions were scanned at higher magnifications to provide characteristic representations of different physical attributes. These flakes were scanned at up to 2000x magnification, but following each episode of use all tools were scanned at 12x to 200x magnification. Ultimately only scans at 100x magnification were analyzed to maximize comparability of results among raw material, use duration and activity categories. This decision was also a matter of analytical practicality given constraints of time. A wider range of magnifications should be used in the future to further test and enhance the results presented here. Once these initial scans were completed these and other flakes were used to scrape both fresh and dry hide, plane and cut fresh juniper wood and to plane bone and antler. While performing each activity all flakes were used in the same manner, including maintaining a constant implement to working surface angle and the application of a constant load and stroke rate, as well as performing all activities on the same contact materials throughout all experimental stages. This was done to maximize consistency of wear production to facilitate comparisons between raw material types. The experiments were designed to incorporate three use-intervals. The first was for ten minutes of continuous use, the second was for an additional 20 minutes resulting in a total of 30 minutes of use between the first and seconds stages, and the third was for a further 30 minutes resulting in a final total of 60 minutes per activity per flake.

After each stage of the experimental program, all tools were subjected to a multi-stage cleansing regimen to maximize trace wear visibility to allow for accurate and reliable analyses of wear accrual patterns. This consisted of initially washing each tool in warm water with mild detergent to remove all visible residues and debris. This was followed by soaking each flake for 30 minutes in a sonic bath of 30% NaOH solution using a Brandon 1510 Sonic Cleaner. Lastly, each tool was rinsed with distilled water to remove any contamination associated with previous handling of the implements. Initially thought was given to including a wash with 10% HCl solution, but since in the prehistoric past adhering residues would have acted as a tertiary abrasive agent the decision was made to omit this step to keep in line with the naturalistic mandate of this study.

Following cleaning the tools were placed in a Hummer VI Sputtering System sputter coater so that they could be coated with a gold-palladium alloy to maximize the conductivity of the sample. Increased conductivity essentially eliminates charging of surface electrons, resulting in much clearer image generation. Each tool was kept in the sputter coater for five minutes per side to ensure it was completely coated with the alloy to a thickness of three nanometers. All flakes were then examined using JEOL JSM-840A and Hitachi 4200 Variable Pressure Scanning Electron Microscopes.

A reasonably wide array of subsistence related activities was initially incorporated into the experimental program and carried out through the first interval of use. This approach yielded a variety of different wear patterns, but the use of one experimental flake per raw material type per activity, while offering insight into wear pattern generation, represents too small a sample for statistical evaluation. Since quantitative testing of observed patterning is a goal of this study it was decided to increase the sample size to demonstrate reproducibility of results and offer a preliminary assessment of experimental error. At the same time, to keep the experimental program manageable, the number of activity types was reduced during the second and third stages to fresh and dry hide scraping and planing juniper. In other words, experiments were subsequently limited to transverse use-motions and to soft to moderately hard contact materials.

The contact materials were obtained from a few different sources. The fresh ungulate hide was acquired from a former student, Brandi Lockhart, whose father is an experienced hunter. The dried ungulate hide was obtained from my thesis supervisor Dr. Michael Bisson. Lastly, Roger Moore of the Chaco Canyon Archaeological Research Centre graciously provided samples of fresh juniper wood, a species indigenous to northern New Mexico and the surrounding area.

Dr. Michael Bisson produced the experimental flake tools through straightforward hard hammer reduction of secondary deposit cobbles. Dr. Bisson generated several flakes of varying shape from each raw material type using both stone and copper percussors. As mentioned previously, every effort was made to restrict flake production to a single nodule of each type, but in the cases of SJF and YSW natural flaws or irregularities necessitated the use of second nodules to obtain the required number of useable flakes. A useable flake is one that possesses an edge angle of 45 degrees or less, that has few if any observable edge or surface irregularities. The tools were not retouched or otherwise modified prior to use, as short-term use implements typically exhibit only use-related edge modification, and in some cases post-depositional alteration. Each experimental tool was bagged separately to prevent any edge damage related to flake-on-flake interaction. All pertinent information for each tool during each stage of experimentation was recorded on three by five inch index cards. This included raw material type, activity type, use duration, stroke count and a plan-view diagram of the tool indicating which edge was used. With each successive stage of experimentation these cards were updated to reflect corresponding increases in use duration and stroke count.

The experiments were carried out with the assistance of five undergraduate students. While due consideration was given to the idea of having the same person conduct the same experiments throughout the entire program, it was decided to let each person perform a range of tasks in order to more accurately replicate the sort of variability inherent in the archaeological record. It is extremely unlikely that in the Late Archaic of northern New Mexico there was sufficient occupational specialization to warrant imposing experimentally a one-to-one relationship between actor and act. A second set of duplicate dry hide working experiments was performed in order to test, in preliminary fashion, the reproducibility and therefore reliability of results.

All tools were hand-held, therefore unhafted, since the short-term production and use of their archaeological counterparts would have made hafting an inefficient and impractical enterprise. Both the wet and dry hides were extended over sheets of plywood and nailed down to restrict their movement during use. The hides were then placed on the laboratory floor where scraping was carried out (*Figures 4.5 and 4.6*).

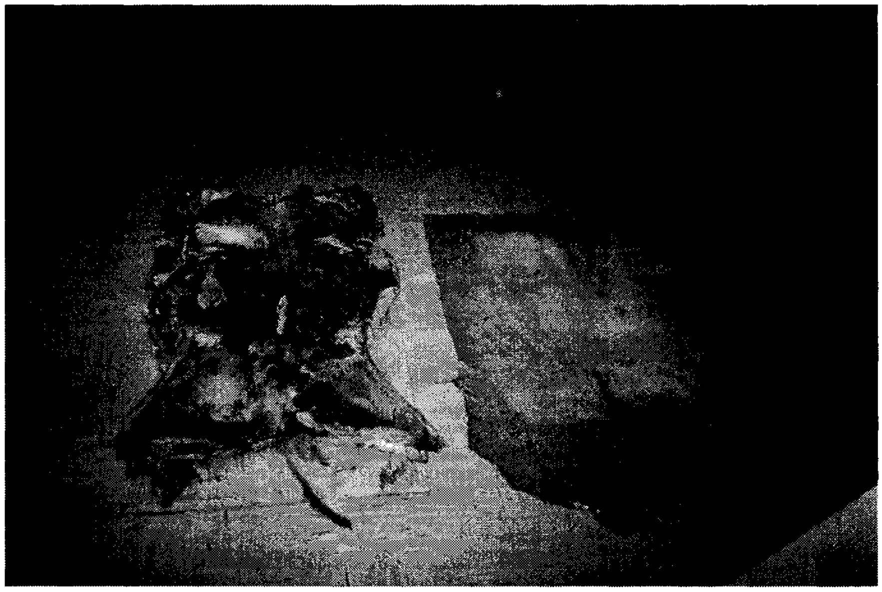


Figure 4.5: Fresh and dry ungulate hides affixed to plywood boards for scraping.

Figure 4.6: Two research assistants; Jennifer Bracewell and Jennifer Dickson, scraping fresh hide.

The Juniper wood was planed while the experimenter was seated. Each specimen was held in one hand and braced against one leg while worked with the tool using the other hand (*Figures 4.7 and 4.8*).

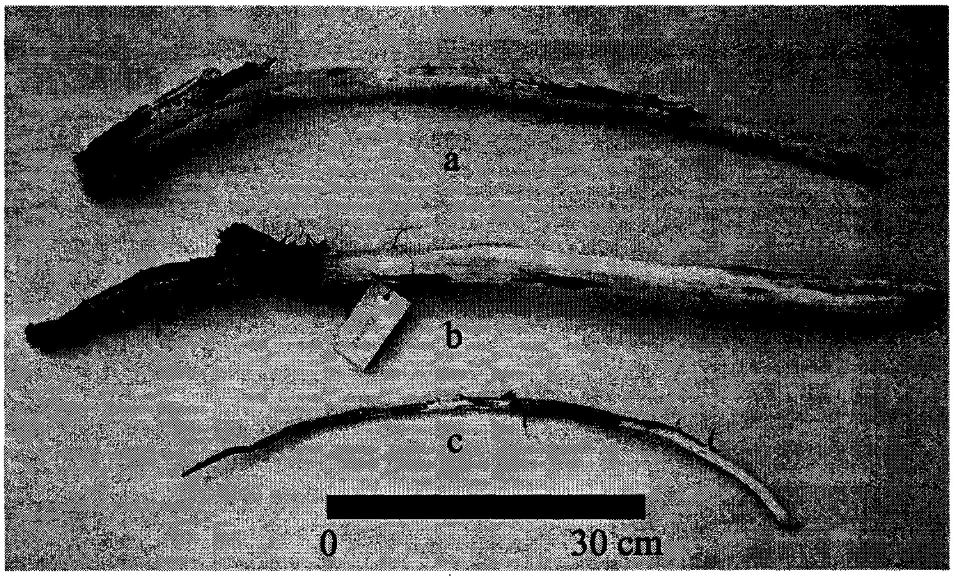


Figure 4.7: Juniper wood used in the planing experiments.


Figure 4.8: Two research assistants; Joanna Rowell and Deanna Dytchkowskyj, planing Juniper wood.

All contact materials were kept as immobile as possible while they were being modified. Each activity was performed in as controlled a manner as possible while still retaining the human element. Each use interval was timed using a digital stopwatch to maximize comparability between both lithic raw material and activity types.

In addition to all the experimental tools examined using SEM another set of experimental tools was made and used for examination using a Leitz Laborlux polarizing incident light microscope. The original idea was to compare results obtained through both techniques of microscopy, but as the analysis progressed it became increasingly obvious that, at least for present purposes, incident light microscopy did not provide any data not accessible through SEM analysis. It was therefore decided to concentrate solely on the SEM data during all analytical components of this study.

It is worth noting that to compliment the research presented here it would also be of interpretive value to examine a single activity type using a larger number of experimental flakes. This would serve to generate statistically testable data regarding variability of wear production within a single activity category. The goal of the current study to develop working hypotheses regarding overall rates of wear accrual as a function of both lithic and contact raw material types, however, is a necessary prerequisite for any further testing of additional sources of variation in patterns of wear development.

To address the nature of trace wear development both digital image and GIS analyses have been carried out. Chapters 5 and 6 respectively detail the results of these investigations. Chapter 7 describes the findings of nanoindentation hardness tests performed on each raw material type in an effort to further assess observed patterns of wear accrual as a function of raw material by quantitatively determining certain physical properties including their respective hardness and surface roughness as a preliminary way of gauging their resistance to wear.

CHAPTER 5: DIGITAL IMAGE ANALYSIS USING CLEMEXVISION PE

It is critical that we consider not only the role of material culture in the prehistoric past, but also its role in contemporary archaeological research. The way in which we approach the analysis of stone tools, like any archaeological remains, directly determines the kind and quality of information we generate about them.

To reiterate, the first aim of this study is to further the analytical utility of raw material type in assessing stone tool life histories and therefore in reconstructing processes of chipped lithic assemblage formation (cf. Goodman, 1944; Greiser and Sheets, 1979; McDevitt, 1994). Before this can be addressed, a few words regarding terminology are necessary. Our perspective on the nature of lithic technologies is directly reflected in the terminology we use to describe and interpret them. In this study, two well-established concepts are reconsidered: *reduction* and *expediency.* Reduction, used to denote the subtractive nature of lithic technology, has most commonly been applied to the production end of the life history spectrum. It has also been discussed with regards to implement maintenance and rejuvenation, but rarely has it been extended to include any other stage of a tool's life history.

The reduction process is a continuous one that does not cease upon the conclusion of one stage and resume later at the start of another, but rather persists throughout the use-life of an artifact, changing only in rate and scale. In the course of use, a tool accrues various forms of wear, including abrasive removal of micro-topographic material and variable-scale edge damage. In other words, reduction continues but has become a byproduct of another process, i.e. use, rather than a desired end itself, as is the case during production. It is also occurring at a reduced rate and scale, but continues to contribute, in a cumulative manner, to changes in the morphology of implements as they progresses through their dynamic life histories.

With regards to tool expediency, as measured by production input, there is often an implicit assumption of limited potential for cultural inference. While these implements experienced use for only a short period of time, this does not preclude their use to the point of exhaustion or their overall potential for shedding light on the people who used them. A few lithic analysts have begun to recognize the interpretive potential of expedient, or as referred to here *short-term use*, technologies (cf. Shott, 1996; Shott and Sillitoe, 2001, 2004), but these implements have yet to systematically receive the kind of analytical attention given regularly to more formal or production intensive technological traditions. The second aim of this dissertation, therefore, is to focus greater research attention on short-term use technologies as a logical starting point for evaluating the nature of use-related attrition as a function of raw material type and resulting implications for cultural interpretation.

This work specifically examines microscopic wear accrual rates as a function of raw material type on short-term use implements from a Late Archaic to Early Basketmaker II site (FA2-13) from northwestern New Mexico as a continuation of reduction processes begun with the initial removal of flake blanks from natural cobbles of various lithic raw materials.

<u>Background of the Present Study</u>

An earlier study of mine on the use-related reduction of a long-term use lithic assemblage from a late prehistoric Huron village in southwestern Ontario (Lerner, 2000) made it clear that the complex nature of such technologies would make even a basic quantitative evaluation of how raw materials influence post-production reduction trajectories difficult at best. As a result, focus was shifted towards short-term use implements because of their relatively uncomplicated life histories. Although this study does not directly address long-term use technologies, it is meant as a first step toward increasing our ability first to reconstruct patterns of wear accrual, and second to identify use-related reduction sequences of both short- and long-term use tools.

To this end the lithic assemblage from the FA2-13 site, located near Farmington, New Mexico, was selected from the collections at the Museum of New Mexico's Laboratory of Anthropology as an ideal test case for a study of raw material variability and its influence on use-wear accrual. This site was excavated as part of the Elena Gallegos Land Exchange in San Juan County (*Figure 5.1*) in the early 1980s. The survey area contains a wide variety of raw material types, including four varieties of silicified wood, at least eleven varieties of chert and two of chalcedony, two kinds of obsidian and various other igneous, sedimentary, and metamorphic materials (Schutt, 1997b: 168-9).

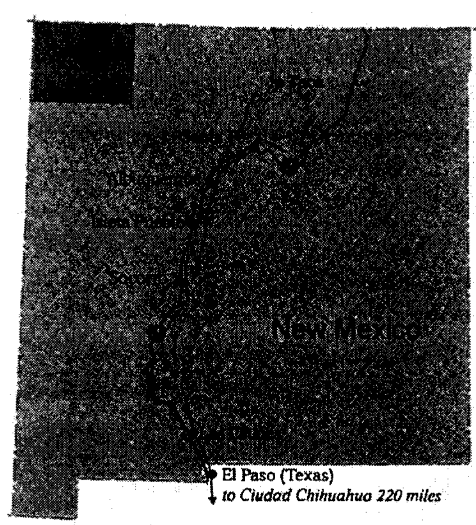


Figure 5.1: General map of New Mexico and the study area, San Juan County.

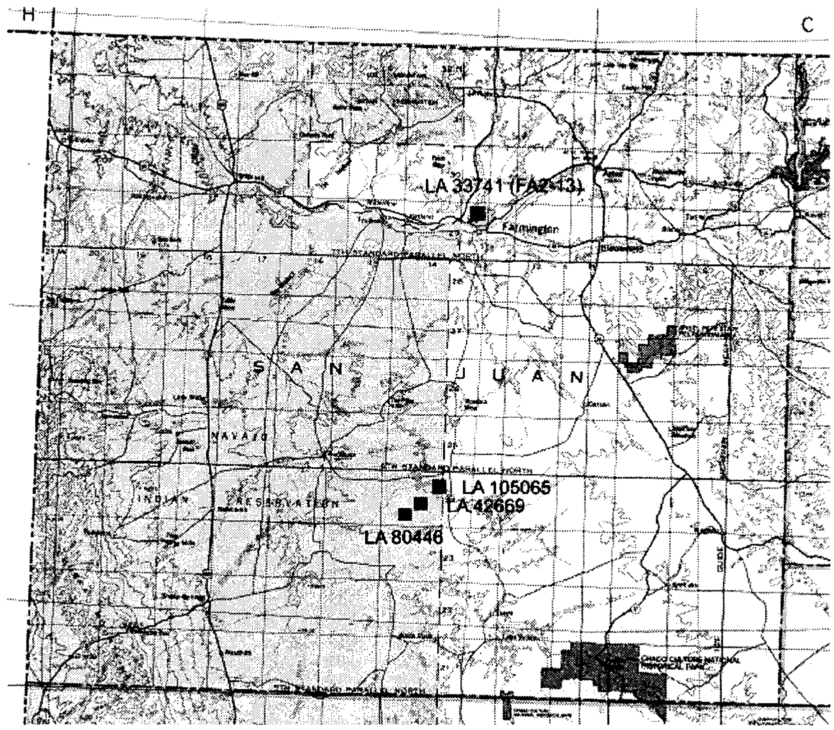


Figure 5.2: Topographic map of San Juan County showing site locations.

FA2-13 was one of four sites (in addition to LA 105065, LA 42669 and LA 80446) slated for further investigation in the Farmington section of the Elena Gallegos project (*Figure 5.2*). FA2-13 dates to the Armijo Phase of the Late Archaic and may have been re-occupied during the Medio/Basketmaker II phases, thus indicating a sequence of repeated occupation from as early as 1800 BC to perhaps as late as AD 200 (Schutt, 1997a: 149). FA2-13 falls chronologically into the latter part of what is referred to as the Oshara or northern Archaic Tradition (Irwin-Williams, 1973.) The Armijo Phase of this tradition has often been characterized by the presence of serrated points with short expanding stems (Ibid: 11), bifacial knives, flake scrapers, drills, choppers and pounders (Cordell, 1997: 109.) Examples of all of these artifacts were recovered during the excavation of FA2-13.

The site, located in a stable dune environment (*Figure 5.3*), consists of three artifact concentrations: a main area, a less dense northeastern area and a northernmost light scattering of material. All three areas are contemporaneous and are considered to be part of a single seasonally occupied camp (Schutt, 1997a). Within the main area three pithouses or semi-subterranean features were recognized and tested (ibid: 153).

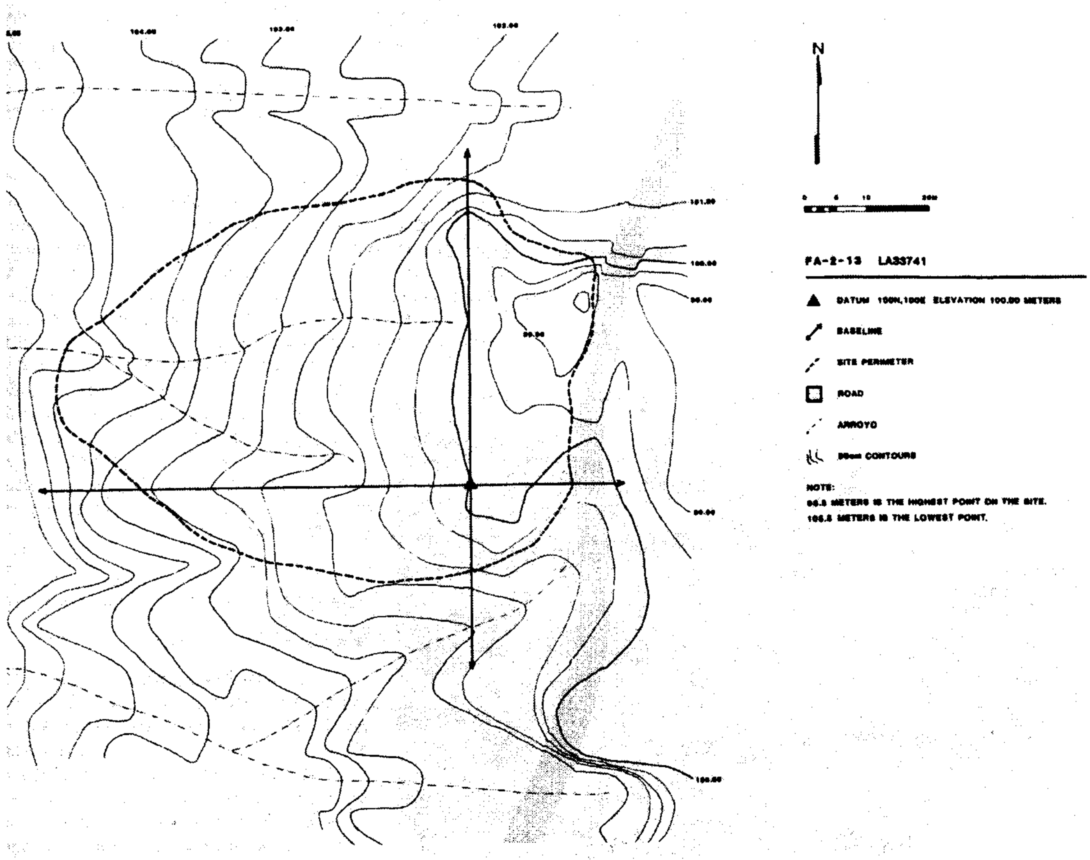


Figure 5.3: Topographic setting of LA 33741 (FA2-13) [reproduced with permission from Schutt 1997a].

The main area of FA2-13 (*Figure 5.4*), from which the bulk of archaeological material from this site derives, consists of a dense accumulation of fire-cracked rock and lithic debris. Given the impracticality of assessing the full range of raw materials recovered from FA2-13 (*Figure 5.5*), the scope of investigation was narrowed to one variety of silicified wood and three cherts (*Figure 5.6*).

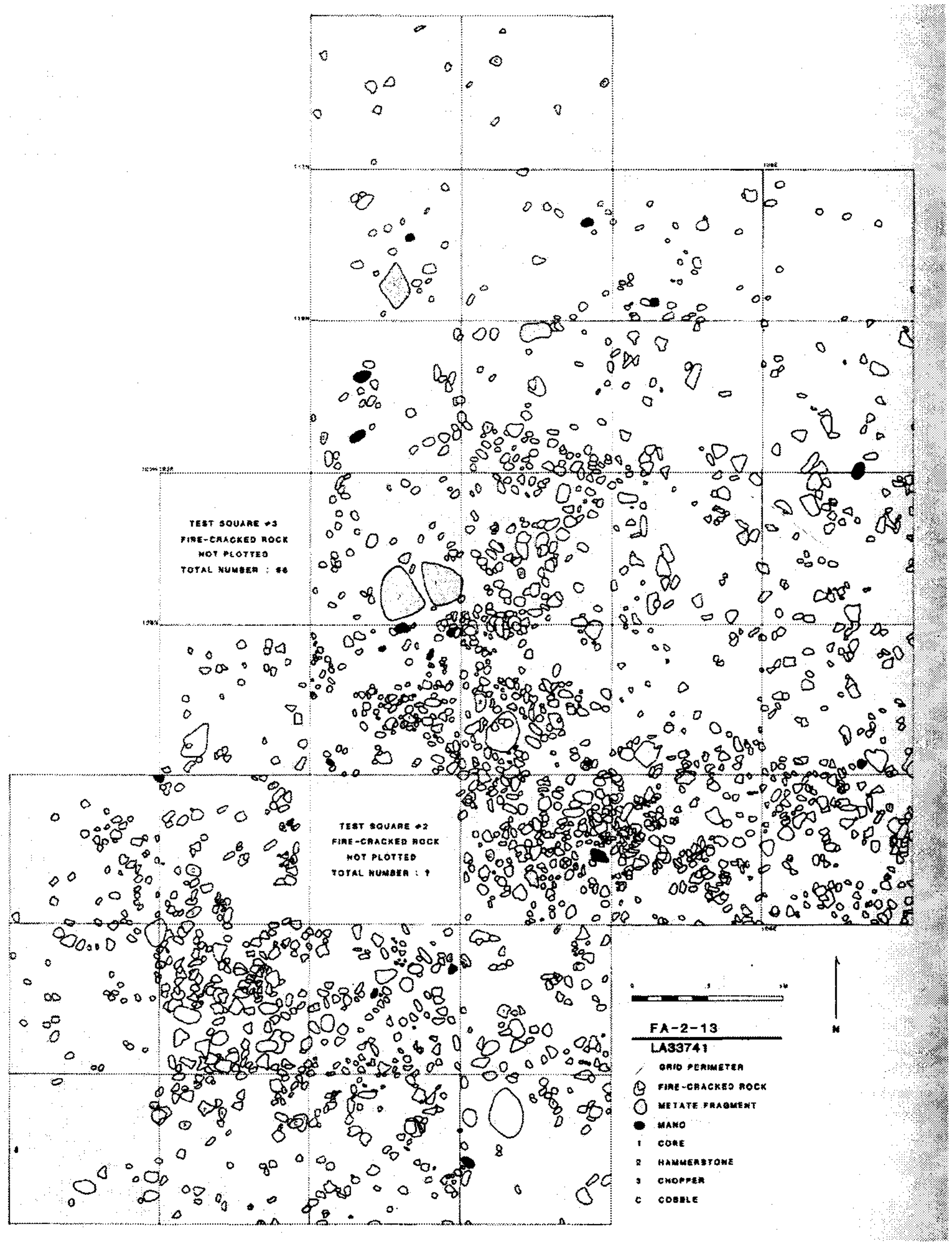


Figure 5.4: The main concentration area at FA2-13 [reproduced with permission from Schutt, 1997a].

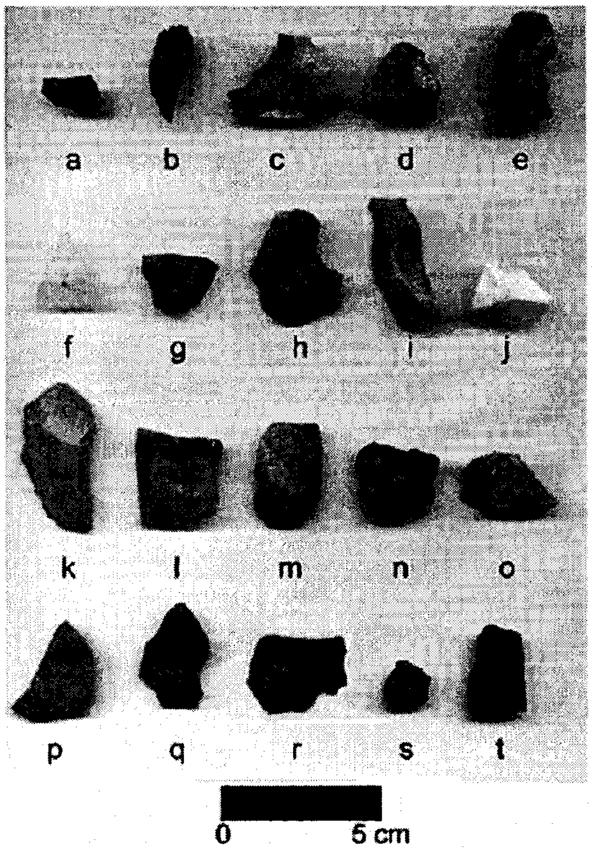


Figure 5.5: Short-tern use flake tools from LA 33741 (FA2-13), including specimens made from YSW, SJF, silicified sandstone and quartzite.

Specifically, I focused my attention on the following four materials: 1) Morrison Undifferentiated Grey chert (MUG), 2) Yellow Silicified Wood (YSW), 3) Brushy Basin chert (BB), and 4) San Juan Fossiliferous chert (SJF).

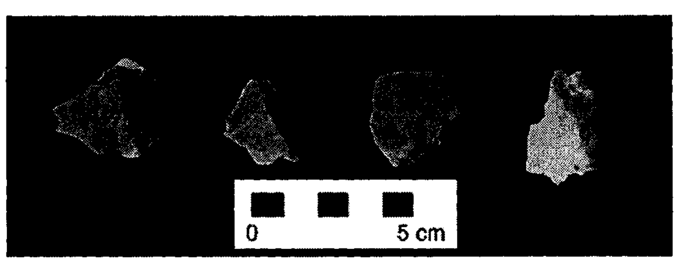


Figure 5.6: The four different raw materials assessed in this paper.

Yellow Silicified Wood and San Juan Chert were chosen for their abundance in the archaeological record of FA2-13. Since they are the only ones represented by reasonable archaeological sample sizes at this site, these two materials represent the entire focus of the archaeological component of this analysis. A sample of ten flake tools (five of San Juan Fossiliferous and five of Yellow Silicified Wood) was examined in an effort to document archaeologically the patterns of use-wear accrual observed among the experimental tools. Attention was focused on this preliminary sample in order to establish an interpretive template designed to facilitate continued analysis of the FA2-13 assemblage and of those from the other sites in the study area. Yellow Silicified Wood and San Juan Fossiliferous Chert are quite different in both appearance and composition. To also evaluate rates of wear accrual among more similar raw materials available in the study area, Brushy Basin and Morrison Undifferentiated Gray Cherts were included in the experimental component of this study for comparative purposes.

To reduce the number of variables involved, the experiments focused on subsistence-related activities that involve transverse use motions, in other words fresh and dry hide scraping and planing Juniper wood. Both the ethnographic and archaeological records document the performance of these activities as part of various subsistence strategies employed by prehistoric peoples throughout the southwest. An area of frequent ethnographic research is the Great Basin of southern California, northern Mexico, Nevada and western Utah and Arizona. The most frequently cited ethnographic work for this area is Julian Steward's *Basin-Plateau Aboriginal Sociopolitical Groups* (1938). Steward provides an extensive account of resource distribution throughout the Great Basin as a way of explicating the spatial organization of human occupation in this area. He describes juniper trees as being native to the mountainous upper Sonoran zone located between 5,000 and 7,000 feet in elevation and, in combination with pinyon, as having served as one of the chief sources of plant food during late summer through early spring (Ibid: 16.) In fact, the lower reaches or area transitional between the lowlands and the higher altitude portion of the Sonoran zone was favoured as location for winter occupations given the reliability of plant foods in this area. (ibid).

Steward goes on to discuss the use of animal foods as part of the Great Basin seasonal round. He states that game was less important than plants as a food source in this area, given the lower sustainability of animal herds in such a dry environment, thus the distribution of natural plant stands was the primary determinant of human migration routes (ibid: 33). The only game species that were the focus of directed hunts were bison and antelope, while other species including deer and mountain sheep were hunted only when and where the opportunity presented itself (ibid). Steward's observations have since been corroborated and expanded upon by other ethnographic researchers (e.g. Bettinger, 1978; Bye, 1972; Davis, 1965; Fowler, 1977; Kelly, 1964.) In *Ethnography of the Northern Utes* Anne M. Smith (1974) describes the construction of shelters in Utah and Colorado that involved the lashing together of four poles and their subsequent draping with coverings made from a range of materials including juniper bark (ibid: 33). She also noted a preference among the Utes for hunting deer supplemented by the occasional pursuit of buffalo, elk, antelope and some smaller animals like rabbit (ibid: 46) and discusses their use of the prepared skins in the manufacture of various items of clothing ranging from loin cloths to full skin attire (ibid: 69).

Ruth M. Underhill (1967) described the past and present lifeways of the Navajo. According to oral histories, as the Navajos entered the Southwest through the mountains of Colorado they engaged in the hunting of several animal species including deer and antelope and used their skins to fashion articles of clothing (ibid: 26). The cultural context of their use of animal resources is presented in all its richness and complexity in Karl W. Luckert's *The Navajo Hunter Tradition* (1975). Complementing the ethnographic data is the archaeological evidence recovered from the Elena Gallegos Project in general and the FA2-13 excavations in particular.

FA2-13 is the largest of the four sites in the Farmington area that were the subjects of more extensive investigation. Along with an account of its excavation and a preliminary evaluation of the recovered lithics (Schutt, 1997a, 1997b), analyses of faunal remains and pollen, as well as studies of food and fuel use at FA2-13, have also been carried out (Bertram, 1997b; Scott Cummings, 1997a; Toll, 1997a). Scott Cummings found juniper pollen on two fragments from the same grinding stone and among the concentration of fire-cracked rocks that comprises the main site area, suggesting the fairly regular use of this tree on this site (Ibid: 326.) This inference is supported by Toll's discussion of general patterns of resource use on FA2-13, in which she notes that among other uses the berries from Juniper trees served as a reliable food source and the wood itself was commonly used as fuel (ibid: 292). In terms of animal foods, Bertram's faunal analysis revealed the presence on FA2-13 of the remains of one or two deer along with those of smaller animals including rabbit (ibid: 260). The kinds of animal and plant resources exploited on FA2-13 point to a late summer through fall and early winter occupation of this site (ibid), which is in keeping with the ethnographic accounts of subsistence behaviour in the American Southwest reported by

Steward (1938) and his successors (e.g. Bettinger, 1978; Fowler, 1977; Smith, 1974.)

Use-wear analyses of both experimental (*Figures 5.7* and *5.8*) and archaeological flake tools (*Figure 5.9)* were carried out to determine if there are recognizable differences in rates of wear accrual attributable to raw material variability.

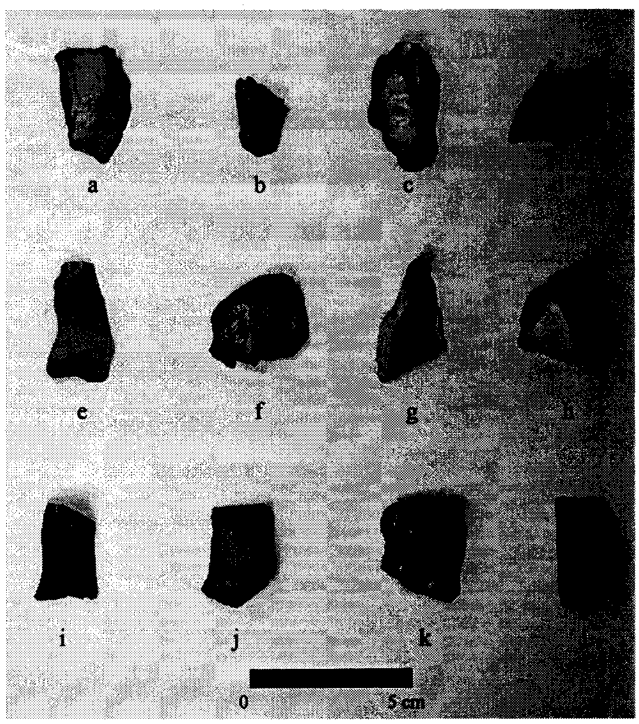


Figure 5.7: The first set of experimental tools with Au/Pd coating. Rows 1 through 3 were used for scraping dry hide, scraping fresh hide and planing juniper wood respectively (BB = a, e, i; SJF = b, f, j; YSW = c, g, k; MUG = d, h, l).

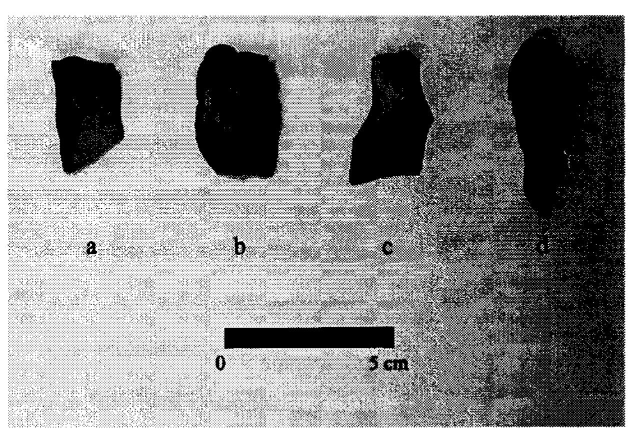


Figure 5.8: The second set of experimental tools used for scraping dry hide (BB = a; SJF = b; YSW = c, MUG =d).

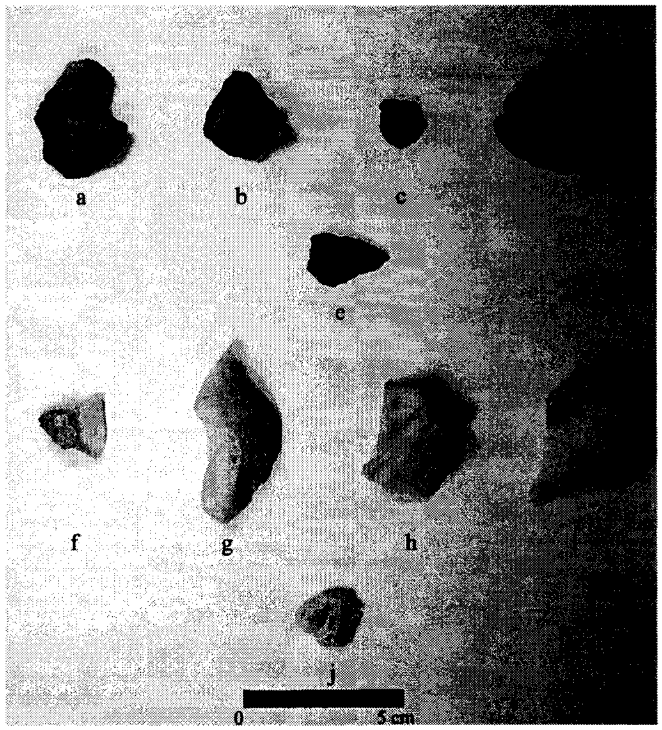


Figure 5.9: Archaeological flake tools analyzed from FA2-13 (YSW = a –e, SJF = f –j).

As describe in Chapter Four, scanning electron microscopy was employed as a way of maximizing the amount of analyzable data from both archaeological and experimentally generated wear traces. While incident light microscopy can be useful for evaluating certain wear attributes in relative terms, such as the brightness of abrasive polishing and the presence or absence of certain surface features, a narrow depth of field limits its overall utility. A much greater depth of field characterizes scanning electron microscopy since it is not subject to the limiting effects of image generation based on the use of a series of glass lenses to direct a beam of light. The use of electrons instead of light allows for higher resolution imaging at much greater magnification, and this in turn permits more detailed analysis of changes in edge and surface attributes over time.

The experiments themselves, which will be discussed in greater detail shortly, were designed with a degree of naturalism in mind. By this it is meant that while certain basic variables were kept as constant as possible, others were allowed to vary naturally to approximate conditions that prevailed prehistorically, generating experimental data that can be compared directly to archaeological material. More rigidly controlled experiments are ideal for evaluating the behaviour of a single variable as part of a larger dynamic process, and hence represent valuable research tools. The aim of the present study, however, is to identify larger-scale patterning in rates of use-wear accrual due to raw material variability. Thus a naturalistic approach to experimentation, in this context, will more readily facilitate archaeological testing of experimental results.

As mentioned in the previous chapter, to better evaluate the effects of raw material type on rates of wear accrual during the performance of these tasks, and thus on the life histories of the implements, a multi-stage experimental design was adopted. These stages are defined by different durations of activity performance ranging from ten to 60 minutes of continuous work. After each stage of experimentation, every tool was subjected to a strict cleansing regimen and detailed microscopic examination to properly monitor patterns of wear accrual.

Each activity was performed in as controlled a manner as possible, while still retaining the human element. As already discussed, to further simulate prehistoric conditions a total of six individuals were involved in carrying out these experiments with no tasks being assigned exclusively to one person such that each participant performed all activities during one stage or another of the experimental program. The following section details how trace-wear generated after each experimental stage was quantified to maximize comparability between raw materials and contact materials, as well as from one stage of the experiment to the next.

Methodology

The research presented here represents an effort to further the interpretive yield of use-wear evidence. To this end, the SEM images generated had to be assessed in as systematically quantitative a manner as possible. Various forms of digital image analysis have been employed since the development in the 1960s of TV-based image analyzers and mathematical representations of morphology (Laferty, 2000.) Highly sophisticated image analysis techniques have often been used as diagnostic tools in the fields of medicine, engineering, and the natural sciences (e.g. Cootes, 2000; Graham, 2000; Parr and Polzleitner, 2001; Rottensteiner, 2001.) Where it has seen relatively limited application is within the social sciences, particularly archaeology. Microwear studies are a perfect example of the sort of social science research that has begun and can continue to greatly benefit from the use of digital image analysis, as evidenced by many advances made over the last quarter century in use-wear analysis and image acquisition (e.g. Evans and Donahue, 2005; Dumont, 1982; Derndarsky and Ocklind, 2001; Grace, 1989, 1990; Grace, Graham, and Newcomer, 1985, 1987; Kimball, Kimball, and Allen, 1995; Stemp and Stemp, 2001, 2003.)

Following each stage of the experiments, resulting SEM images were imported into the ClemexVision Professional Edition (Version 3.5) image analysis software package for quantitative analysis of specific wear attributes (*Figure 5.10*). Once the program acquired an image, it was then converted into binary format through the use of a series of filters that reconfigured the image to highlight specific areas of interest in order to facilitate their quantification (*Figure 5.11 a* and *b*). Pixels falling within a specified range of gray values were assigned to what is referred to as a bitplane, and distinguished visually by a specific colour. In Figures 5.10 through 5.12 the lighter gray is red and the darker gray is blue when viewed in the Clemex program. Each bitplane represents a separate layer within the larger image that allows independent measurement and subsequent comparison.

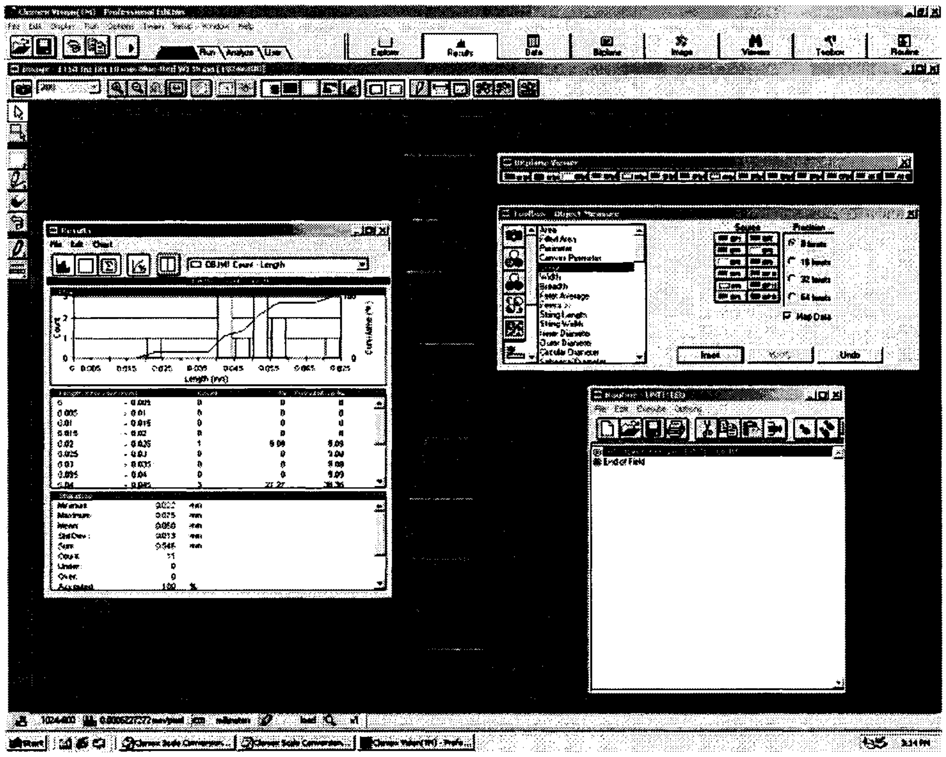
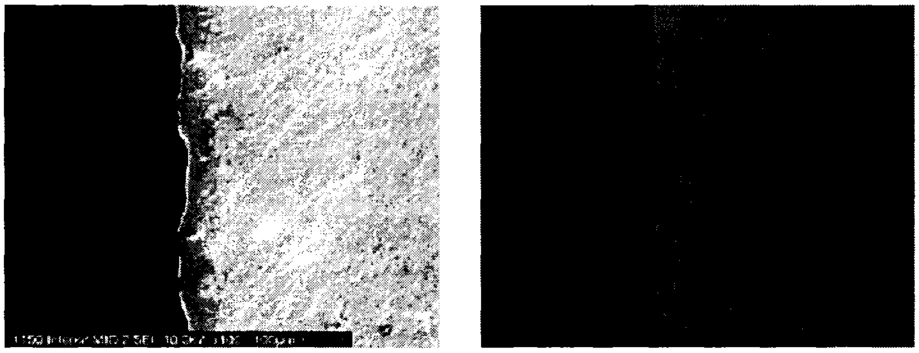


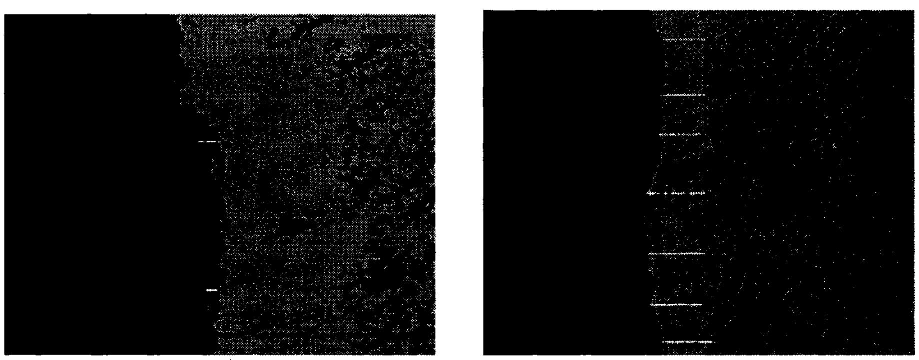
Figure 5.10: Screen capture of the Clemex Vision digital image analysis software.

The binary version of each image was then assessed according to type and extent of wear. Specifically, degree of edge modification and overall invasiveness (*Figures 5.12 a* and *b* respectively) were measured by determining the length of several lines superimposed along the tool edge for each attribute. Since wear does not develop uniformly over an entire tool surface, it was decided to measure each trait at multiple locations to obtain statistically representative mean values for each image. The lines representing edge rounding were assigned to their own bitplane or layer, as were the lines denoting wear invasiveness. There are several other attributes that can be evaluated using the Clemex system, including edge roughness, edge roundness and microtopographic feature surface area, among others. However, for the present purpose of identifying any wear accrual patterning as a function of raw material, as well as testing the utility of Clemex Vision as an effective tool for microwear analysis, attention was focused on the variables discussed above.



a b

Figure 5.11: An SEM image (a) before and (b) after binary conversion.



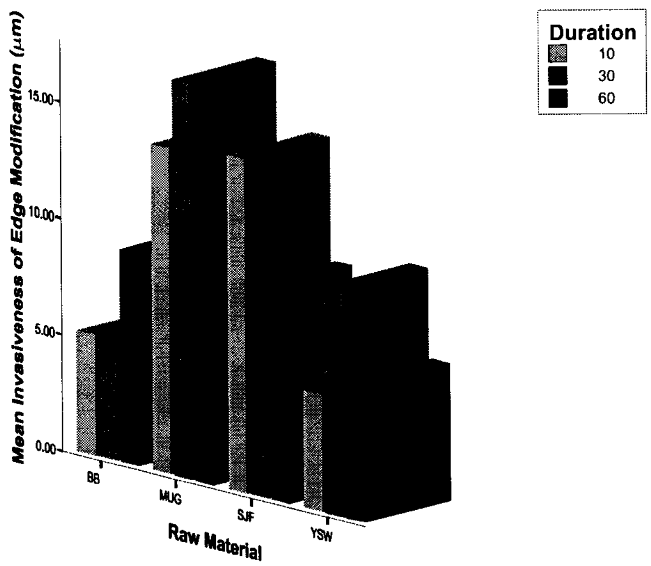
a b

Figure 5.12: Measurement of (a) edge modification and (b) overall wear invasiveness (these images are close-ups carried out in the Clemex program of the 100x SEM scan of this tool).

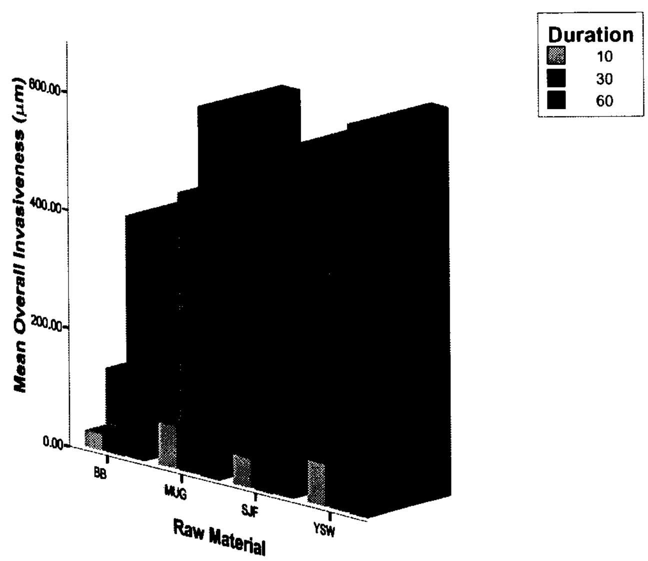
The archaeological tools chosen for analysis exhibit little or no evidence of chemically based surface modification, thus minimizing the obscuring effects of any non-use-related taphonomic processes.

Results

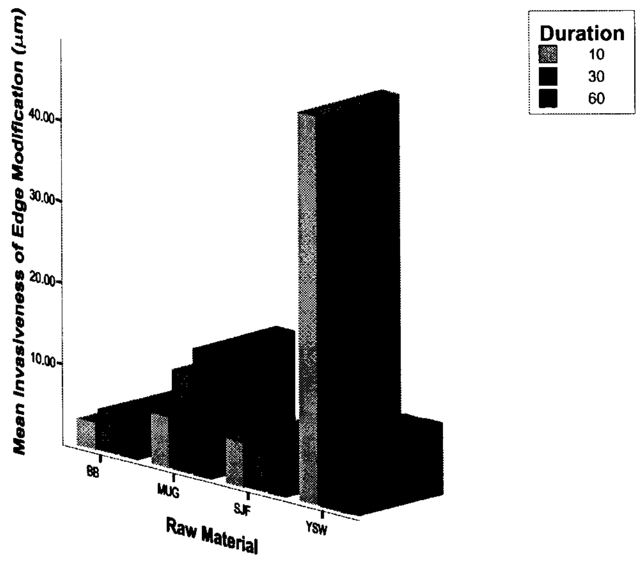
The following bar graphs illustrate the results for invasiveness of edge rounding for dry hide scraping, a combination of rounding and microfracturing for fresh hide, microfracturing for wood planing and overall wear invasiveness for all contact materials as a function of raw material type. Individual bars were omitted from the graphs if no use-related wear was detectable. The raw data are presented in Table 5.1.



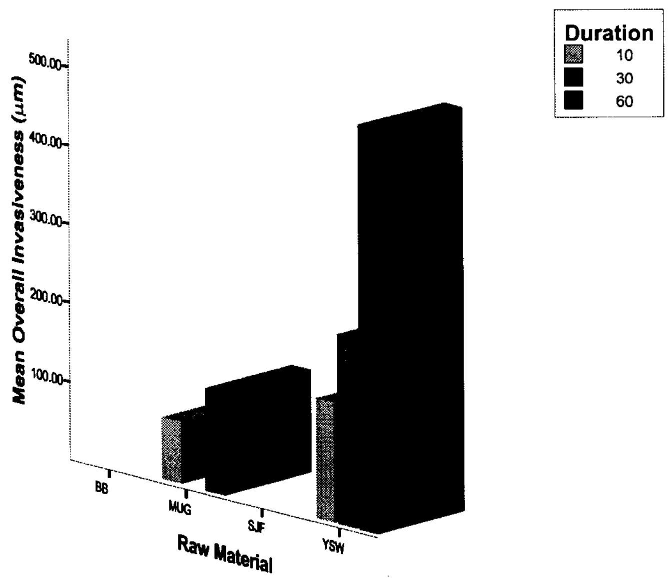
a



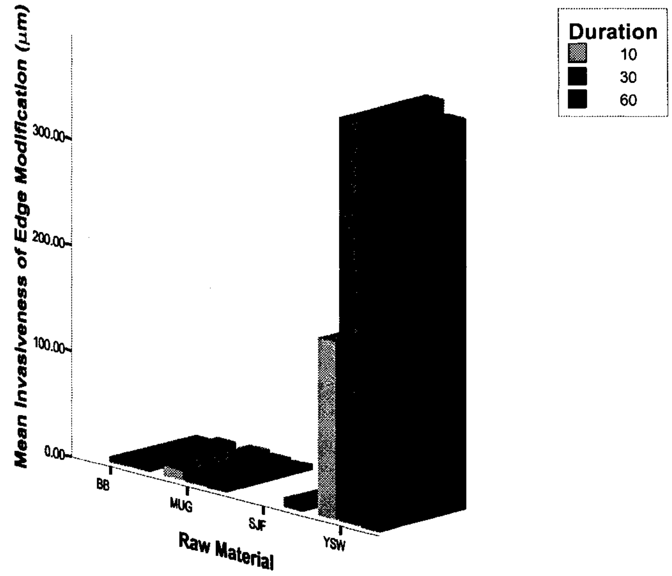
b


Mean Invasiveness of Edge Modification (μm)
40.00
30.00
20.00
10.00
BB
MUG
SJF
YSW
Raw Material
Duration
10
30
60

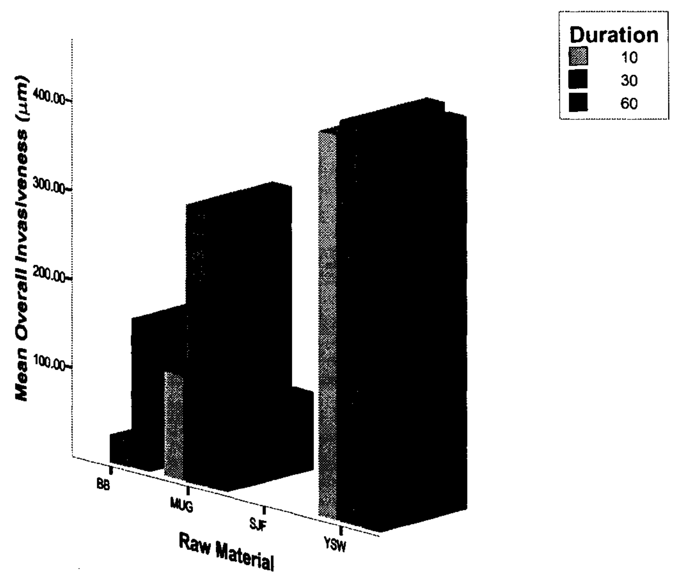
c


Mean Overall Invasiveness (μm)
500.00
400.00
300.00
200.00
100.00
BB
MUG
SJF
YSW
Raw Material
Duration
10
30
60

d



e



f

Figure 5.13: Bar graphs illustrating extent of edge modification and overall wear invasiveness for (a, b) scraping dry hide, (c, d) scraping fresh hide, and (e, f) planing Juniper wood.

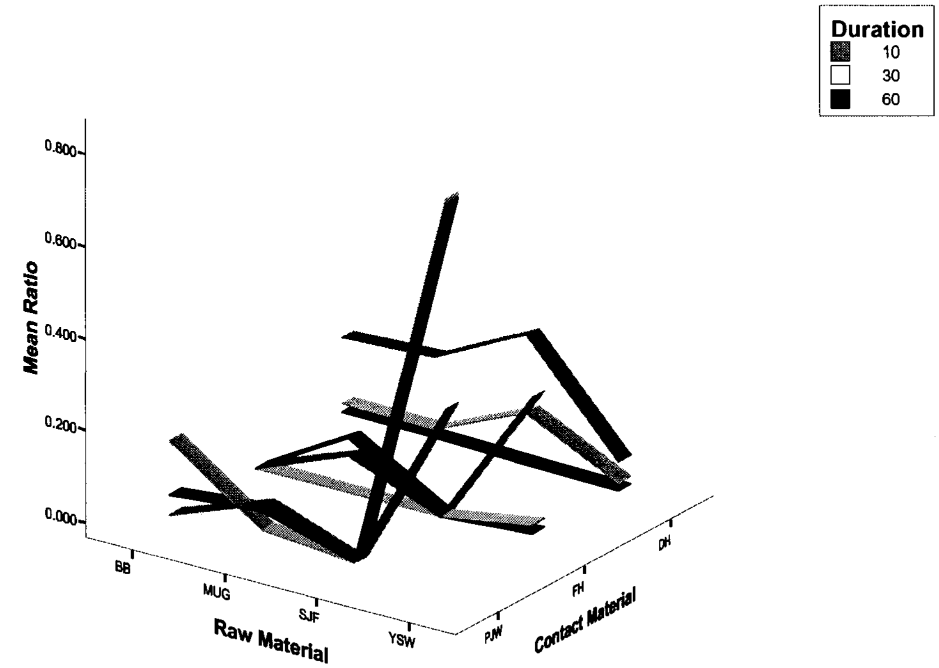


Figure 5.14: Three-dimensional line graph of edge modification to overall wear invasiveness ratios.

Figures 5.13 a and b represent rates of wear accrual when scraping a dry ungulate hide for 10, 30, and 60 minutes. Edge rounding (*Figure 5.13 a*) appears to develop quite differently from one raw material to the next. With the exception of Brushy Basin (BB) there is at least one decrease in the extent of edge rounding throughout the entire experiment. This is most likely due to the loss of material through edge crushing. Material composition and edge thickness are significant factors in determining likelihood of edge failure. The steady decrease in edge rounding observed for San Juan Fossiliferous (SJF), for example, may be due to the large number of micro-fossil inclusions, thus increased tendency towards collapse relative to a more homogeneous material such as Brushy Basin.

Overall wear invasiveness for the scraping of dry hide presents a much clearer picture of how raw material type affects wear accrual rates. Invasiveness (*Figure 5.13 b*) demonstrates that through all three stages of the experiment Yellow Silicified

Wood (YSW) accrued wear most rapidly. After 10 minutes of use YSW exhibited the most invasive wear, after 30 minutes Morrison Undifferentiated Gray Chert (MUG) exhibited the greatest degree of invasiveness and after 60 minutes YSW again had the most invasive wear. Initially this would seem to suggest some inconsistency in how these materials behaved from one stage to the next, but through all of them use-wear accrual on YSW was far more homogeneous, i.e. affected a much greater percentage of tool surface area, including both microtopographic peaks and valleys, than any of the other three materials.

The pronounced differences in how the four raw materials responded under equivalent conditions of use has serious implications for assessing both tool function and use intensity, particularly regarding short-term use implements, as will be discussed below. Scraping fresh ungulate hide (*Figures 5.13 c* and *d*) also resulted in noticeable differences in rates of edge rounding between the four different raw materials. In this case, San Juan Fossiliferous was the only material to experience significant edge collapse between the 30 and 60-minute stages of the experiment. The softness and moisture of fresh hide reduces the amount of friction generated during use resulting in fewer instances of edge failure and in overall slower rates of edge rounding compared to scraping dry hide.

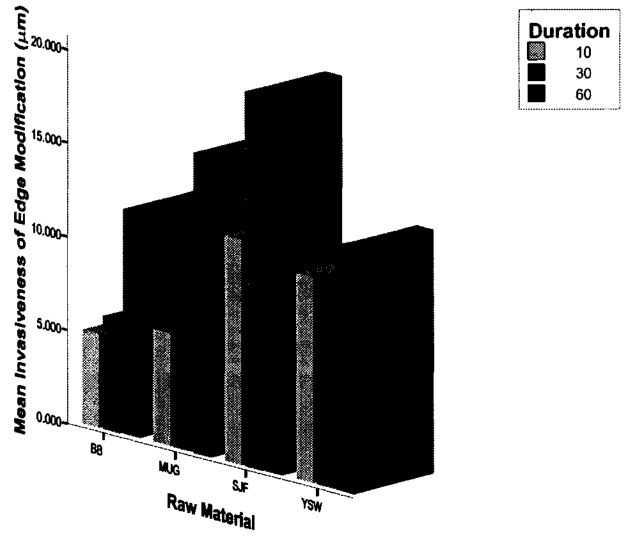
Wear invasiveness patterning for fresh hide parallels that seen for dry hide but is less pronounced overall. Yellow Silicified Wood accrued wear most readily during the 30 and 60 minute stages, in fact Yellow Silicified Wood and Brushy Basin were the only materials to exhibit wear after 30 minutes of use, and Brushy Basin was the only one to exhibit wear after 10 minutes of use. The results from planing Juniper wood (*Figures 5.13 e* and *f*), in part, had to be assessed somewhat differently than those produced for scraping hide. Since edge rounding is not a wear characteristic typically associated with planing wood (c.f. Keeley, 1980; Vaughan, 1985) any evidence of edge modification was measured in its place. The invasiveness, or depth, of microfracturing, for example, was employed when dealing with Yellow Silicified Wood as an alternative means of looking at edge modification as this material exhibited invasive microfract-uring, while the other three raw materials exhibited either minimal microfracturing or none at all.

Apart from Yellow Silicified Wood, Morrison Undifferentiated Gray was the only other material to exhibit any edge wear after 10 minutes of use. Brushy Basin exhibited edge wear only after 30 minutes of use and San Juan only after 60 minutes of use. Overall wear invasiveness again demonstrated that Yellow Silicified Wood accrued wear most readily. Only Yellow Silicified Wood and Morrison Undifferentiated Gray accrued wear after 10 minutes of use, Brushy Basin did so only after 30 minutes, and San Juan did not accrue any significant amount of wear apart from some slight edge attrition.

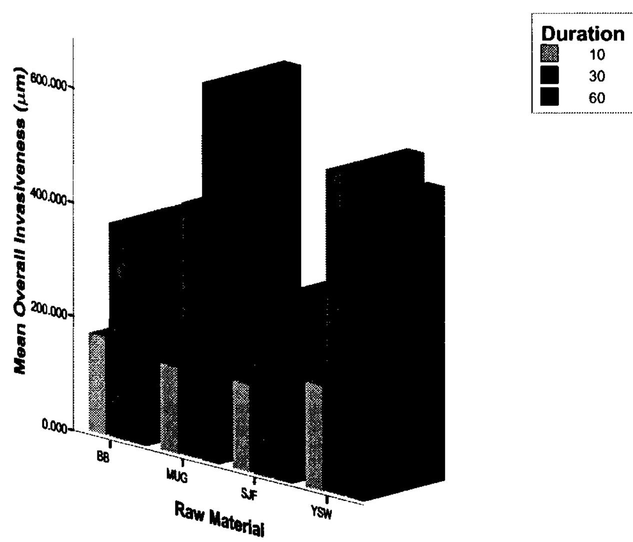
Figure 5.14 is a three-dimensional line graph that compares the ratio of edge modification to overall wear invasiveness across raw material and contact material categories through all three stages of the experimental program. This ratio was calculated to assess and compare respective rates of change in these two wear attributes in order to identify any patterning as functions of the aforementioned variables. Dry hide scraping results in a much faster rate of wear invasiveness than edge modification, in this case rounding, than does scraping fresh hide. The pattern for planing Juniper wood is heavily influenced by the prominent microfracturing seen with Yellow Silicified Wood, but is otherwise suggestive of minimal edge modification in conjunction with a lesser degree of wear invasiveness compared to scraping either dry or fresh hide.

From one experimental stage to the next, dry hide scraping resulted in marked decreases in the value of this ratio for all raw material types, with Yellow Silicified Wood having the lowest values at all three stages, San Juan having the highest through the first two stages of experimentation and Brushy Basin having the highest after 60 minutes of use. Fresh hide scraping yielded generally lower if less clearly patterned ratio values, with Yellow Silicified Wood again being associated with the lowest values, but in this case Brushy Basin generated the highest values overall. Planing Juniper wood is characterized by the opposite pattern to that seen with hide preparation, but again this is most likely due to the prominence of microfracturing on Yellow Silicified Wood.

A second set of four experimental flake tools was used to again scrape dry hide to test in a preliminary fashion the reproducibility of results (*Figure 5.15 a* and *b*, *Table 5.22*). As with the first set of dry hide scraping tools, rates of edge modification varied in different ways, with San Juan again having the highest rate through the first two stages and Brushy Basin having the lowest. Again like the first set, after 60 minutes of scraping Morrison Gray exhibited the highest degree of edge modification, which is likely due, in part, to episodes of edge collapse experienced by some of the other materials. It is important to note that there are certain wear accrual pattern differences between the two sets of experimental dry hide scraping tools. This can be attributed to the simple fact that no two flakes of the same raw material are absolutely identical; therefore they will not respond to the applied forces incurred during use in exactly the same way.



a



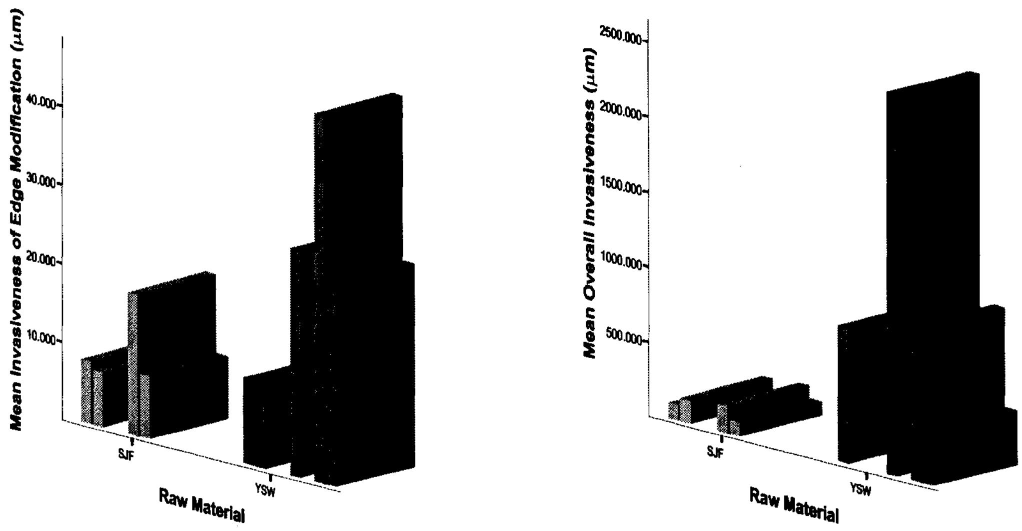
b

Figure 5.15: Bar graphs illustrating extent of edge modification and overall wear invasiveness for (a, b) the second set of dry hide scraping tools.

Patterns of overall wear invasiveness were also largely the same as seen with the first set of tools. Yellow Silicified Wood accrued wear most rapidly followed by Morrison Gray, Brushy Basin, and San Juan in decreasing order, with this pattern being clearest after 30 minutes of use. Two notable differences are that Brushy Basin and Yellow Silicified Wood experienced edge collapse between the 30 and 60-minute stages and that in the first set of dry hide scraping experiments Morrison Gray and Brushy Basin were reversed in the sequence of decreasing rates of wear accrual. Overall, the same patterns emerged within both sets of dry hide scraping tools although they still exhibited certain differences due to inherent individual flake properties.

Following evaluation of the experimental tools, five archaeological flake tools each of Yellow Silicified Wood and San Juan were subjected to the same analytical procedures to see if wear patterns similar to those generated experimentally could be observed archaeologically. As mentioned earlier, archaeological attention was focused exclusively on Yellow Silicified Wood and San Juan due to these two materials being the most extensively exploited on FA2-13. These artifacts were selected for the absence of any patination, heat treatment, or other forms of chemical surface alteration to ensure minimal destruction of any wear traces. The most obvious similarity between the experimental and archaeological sets of tools was the systematic presence of more extensive wear on tools made from Yellow Silicified Wood than from San Juan (*Figure 5.16 a* and *b*, *Table 5.3*).

This, however, does not necessarily imply that the Yellow Silicified Wood tools were used more intensively than their San Juan counterparts. Given the experimental results presented above, the influence of inherent raw material properties must be taken into account when assessing these wear traces in terms of both inferred function and use intensity. Based on comparisons with the experimental results, the Yellow Silicified Wood flakes with highly invasive wear may have been used to scrape dry hide, but not necessarily for a much longer period of time as one might assume when compared to the San Juan flakes. The Yellow Silicified Wood flake that showed



a b

Figure 5.16: Bar graphs illustrating extent of edge modification (a) and overall wear invasiveness (b) for archaeological tools from FA2-13.

evidence of edge modification but no significant invasive wear may have been used somewhat more intensively to work fresh hide, for example, which tends to produce invasive wear at a slower rate than scraping dry hide. Also, the flake of San Juan Fossiliferous Chert that exhibited no evidence of wear may still have been used, but due to the nature of this particular variety of chert, just not to the point when evidence of wear first appears.

Discussion

The results above highlight some important issues regarding how we currently deal with archaeological wear traces and how we should be dealing with them in the future. It has been demonstrated that raw material properties can have a pronounced effect on how wear develops over time. This finding requires that we consider these effects when making inferences about the nature of tool use. We cannot assume that extensive wear implies longer use and that little or no wear implies limited use. Yellow Silicified Wood accrued wear most rapidly, and after 60 minutes of use in each activity exhibited greater wear than any of the other materials tested, except for the second set of dry hide scraping experiments when edge collapse effectively reduced overall wear invasiveness values for this material. Equal amounts of use resulted in very different rates of wear accrual from one raw material to the next. This illustrates that extent of use-wear is not always a reliable measure of duration, but a better understanding of observed differences can offer insight into activity intensity and therefore significance as part of larger subsistence strategies.

The analysis of ten flake tools from the FA2-13 site revealed that the faster and slower rates of wear accrual experimentally attributed to Yellow Silicified Wood and San Juan respectively can be observed archaeologically. As stated by Schutt (1997a: 164), several subsistence-related tasks were carried out at FA2-13 with preliminary wear evidence suggesting an emphasis on scraping activities. The results presented here do not dispute this assertion but offer the potential for greater insight into the nature of this emphasis than previously possible and thus the promise of a far more detailed reconstruction of the prevailing subsistence strategy.

It is interesting to note that when I first obtained access to the FA2-13 chipped lithics three years ago, examinations using a Leitz Laborlux high-power metallurgical incident light microscope were carried out to determine if any identifiable wear traces could be observed on such short-term use implements. The Yellow Silicified Wood artifacts consistently exhibited more homogeneous and extensive abrasive wear compared to the San Juan tools, thus were tentatively identified as having been used to work different contact materials, pending comparison to experimental data. In light of the experimental results presented above, those initial examinations can now be viewed as a series of informal blind tests that, in hindsight, highlight the pronounced influence assumptions regarding the significance of differences in use-wear attributes can have our interpretations. The above results strongly illustrate the need for increasingly systematic quantification of wear attributes and for careful consideration of how raw material physical properties affect the nature of wear accrual.

While the present study concentrated on examining the invasiveness of edge and adjacent surface wear, the application of digital image analysis techniques holds great promise as a tool for cultural interpretation. Along with Clemex Vision's ability to significantly increase comparability of wear traces as they develop over time and appear on one raw material relative to another, it boasts a long list of analytical measures, including edge roughness, edge roundness, and surface area calculations, for example, that have the potential for providing considerable insight into patterns of wear accrual.

The promise of digital image analysis in archaeological use-wear research is considerable. It has the potential to offer, for example, a more systematic means of dealing with microfracture morphology. The ability to digitally assess this and other attributes may even pave the way towards more consistent methods of distinguishing between patterns of cultural and natural wear. These future applications can then collectively serve as an increasingly reliable basis for generating inferences about tool use behaviour in particular and past cultural dynamics in general.

Raw Material	Contact Material	Duration (min)	Edge Min	Edge Max	Interior Min	Interior Max	Edge Mean	Interior Mean	Mean Ratio
SJF	Dry Hide	10	5.26	19.99	27.36	93.19	14.33	48.45	0.296
SJF	Dry Hide	30	4.21	18.94	31.57	136.20	9.06	72.20	0.125
SJF	Dry Hide	60	3.21	10.73	459.81	650.34	7.73	583.38	0.013
BB	Dry Hide	10	2.15	8.58	13.95	45.07	5.15	27.79	0.185
BB	Dry Hide	30	3.22	7.51	107.32	179.22	5.58	141.12	0.040
BB	Dry Hide	60	4.29	22.54	283.32	514.05	9.12	408.13	0.022
YSW	Dry Hide	10	2.11	11.58	26.31	96.82	5.05	71.45	0.071
YSW	Dry Hide	30	4.21	31.57	337.83	434.65	9.79	397.81	0.025
YSW	Dry Hide	60	3.22	11.81	560.08	850.87	5.90	657.86	0.009
MUG	Dry Hide	10	9.00	19.00	64.00	90.00	14.00	72.00	0.194
MUG	Dry Hide	30	8.00	26.00	434.00	512.00	17.00	470.00	0.036
MUG	Dry Hide	60	5.36	21.46	489.37	688.98	12.34	624.91	0.020
SJF	Fresh Hide	10	2.14	8.58	0.00	0.00	5.47	0.00	0
SJF	Fresh Hide	30	2.14	18.24	0.00	0.00	6.65	0.00	0
SJF	Fresh Hide	60	2.14	15.02	0.00	0.00	5.15	0.00	0
BB	Fresh Hide	10	2.14	6.54	0.00	0.00	3.33	0.00	0
BB	Fresh Hide	30	3.22	8.58	0.00	0.00	5.04	0.00	0
BB	Fresh Hide	60	3.22	9.66	0.00	0.00	5.37	0.00	0
YSW	Fresh Hide	10	11.68	99.78	145.43	157.11	47.98	152.68	0.314
YSW	Fresh Hide	30	3.18	31.85	163.48	339.69	8.81	241.39	0.036
YSW	Fresh Hide	60	3.18	19.11	437.35	580.66	8.92	514.36	0.017
MUG	Fresh Hide	10	3.22	10.73	13.95	129.85	6.22	79.03	0.079
MUG	Fresh Hide	30	4.29	22.54	0.00	0.00	12.34	0.00	0
MUG	Fresh Hide	60	9.65	23.61	65.46	180.29	15.56	131.25	0.119
SJF	Planing Wood	10	0.00	0.00	0.00	0.00	0.00	0.00	0
SJF	Planing Wood	30	0.00	0.00	0.00	0.00	0.00	0.00	0
SJF	Planing Wood	60	6.35	14.81	0.00	0.00	9.10	0.00	0
BB	Planing Wood	10	0.00	0.00	0.00	0.00	0.00	0.00	0
BB	Planing Wood	30	2.00	8.00	11.00	55.00	5.00	31.00	0.161
BB	Planing Wood	60	3.18	19.08	84.80	228.96	7.42	168.54	0.044
YSW	Planing Wood	10	149.17	184.58	341.04	567.71	168.17	433.48	0.388
YSW	Planing Wood	30	358.44	415.32	422.83	518.34	382.16	452.45	0.845
YSW	Planing Wood	60	347.71	401.36	418.54	510.83	369.06	442.58	0.834
MUG	Planing Wood	10	3.18	21.20	60.42	241.68	8.48	116.60	0.073
MUG	Planing Wood	30	4.24	9.54	243.80	381.60	6.36	312.70	0.020
MUG	Planing Wood	60	2.12	11.66	33.92	250.16	5.30	87.98	0.060

Table 5.1: Edge modification and overall wear invasiveness data generated using Clemex Vision for the first set of experimental tools (all measurements in μm).

Raw Material	Contact Material	Duration (min)	Edge Min	Edge Max	Interior Min	Interior Max	Edge Mean	Interior Mean	Mean Ratio
SJF	Dry Hide	10	6.00	18.00	104.00	196.00	12.00	152.00	0.079
SJF	Dry Hide	30	14.00	27.00	94.00	285.00	20.00	199.00	0.101
SJF	Dry Hide	60	3.00	10.00	224.00	453.00	6.00	322.00	0.019
BB	Dry Hide	10	3.00	7.00	140.00	188.00	5.00	170.00	0.029
BB	Dry Hide	30	3.00	11.00	264.00	420.00	6.00	374.00	0.016
BB	Dry Hide	60	3.00	21.00	127.00	256.00	12.00	198.00	0.061
YSW	Dry Hide	10	7.00	17.00	139.00	227.00	11.00	183.00	0.060
YSW	Dry Hide	30	7.00	14.00	404.00	739.00	10.00	565.00	0.018
YSW	Dry Hide	60	3.00	20.00	458.00	559.00	13.00	515.00	0.025
MUG	Dry Hide	10	4.00	11.00	81.00	217.00	6.00	149.00	0.040
MUG	Dry Hide	30	5.00	17.00	371.00	525.00	9.00	442.00	0.020
MUG	Dry Hide	60	10.00	31.00	339.00	834.00	16.00	661.00	0.024

Table 5.2: Edge modification and overall wear invasiveness data generated using Clemex Vision for the second set of experimental dry hide scraping tools (all measurements in μm).

Raw Material	Find Spot No	Edge Min	Edge Max	Interior Min	Interior Max	Edge Mean	Interior Mean	Mean Ratio
SJF	898	1.00	6.00	14.00	33.00	214.00	8.00	0.073
SJF	1032	1.20	2.00	13.00	82.00	268.00	7.00	0.043
SJF	1082	1.40	9.00	38.00	144.00	225.00	18.00	0.100
SJF	1087	1.60	4.00	15.00	25.00	234.00	8.00	0.087
SJF	1137	1.80	0.00	0.00	0.00	0.00	0.00	0.000
YSW	1040	2.00	3.00	24.00	766.00	1155.00	11.00	0.012
YSW	1059	2.20	6.00	13.00	0.00	0.00	10.00	0.000
YSW	1131	2.40	14.00	54.00	2195.00	2830.00	29.00	0.011
YSW	1149	2.60	10.00	183.00	776.00	1236.00	47.00	0.046
YSW	1156	2.80	4.00	71.00	157.00	476.00	26.00	0.071

Table 5.3: Edge modification and overall wear invasiveness data generated using Clemex Vision for archaeological tools from FA2-13 (all measurements in μm).

CHAPTER 6: GIS ANALYSIS OF TOOL SURFACE MICROTOPOGRAPHY USING IDRISI KILIMANJARO

The digital image analyses of both experimental and archaeological wear traces detailed in the preceding chapter identified clear differences in the rates at which the four raw materials in question accrued wear under equivalent conditions of use. These results were achieved due to the systematic quantification of wear invasiveness made practical and effective by the ClemexVision software. While this program has demonstrated that it should become a standard component in the lithic use-wear analyst's methodological arsenal, it is not without its limitations. Having been designed for metallurgical analysis, and thus to be used with materials possessing minimal surface microtopography, it is largely two-dimensional in its analytical scope.

Unlike metal alloys, lithic materials tend to be heterogeneous in nature. This heterogeneity not only varies from one raw material 'type' to another, but can also be quite variable from one specimen to the next. As mentioned in Chapter 3, this is certainly the case with the materials presently being considered. It is particularly true for San Juan Fossiliferous Chert, as the nodules acquired for experimentation ranged from being essentially cryptocrystalline in nature, apart from the microfaunal inclusions, to a nearly granitic coarseness. It once again brings into serious question the utility of traditional raw material 'types' as meaningful organizational categories and underscores the need for incorporating systematic evaluations of raw material physical characteristics as part of the standard analytical protocols employed in use-wear studies.

The highly heterogeneous nature of lithic materials significantly increases the complexity of wear accrual patterns warranting the inclusion of other analytical techniques that permit their full and proper assessment. One of these techniques, geared specifically to gauge microtopographic variability as a function of raw material properties, involves the application of Geographic Information Systems (GIS) analysis as a way of directly quantifying changes in tool surface roughness throughout the course of use. Using GIS in tandem with digital image analysis facilitates evaluation of wear accrual rates in three dimensions. As shown in the last chapter, digital image analysis using ClemexVision is a highly effective means of determining, in terms of wear invasiveness, how different raw materials behave under equivalent conditions of use. GIS compliments digital image analysis by making possible the measurement of microtopographic variability that provides the third dimension of analysis not readily available through ClemexVision.

This next section will provide some background on the role to date GIS has played in archaeological research. This will be followed by a detailed account of the present application of GIS technology and the results obtained. These results will be considered not only on their own terms but also in conjunction with those obtained through digital image analysis to more comprehensively assess their collective implications for the present case study and use-wear analysis in general.

GIS and Archaeology

Since archaeology was first recognized as a formal intellectual discipline, the structure and organization of the archaeological record has been of primary interest. As innovations in analytical technology were developed, so did the methods employed in archaeological research. During the late 1970s the advent of computer technology opened up a world of analytical possibilities never previously considered much less available to archaeologists. The study by J. E. Estes *et al* (1977) of two California Mission sites using an early form of digital image transformation of historic photographs, is one of the earliest examples of digital analysis of archaeological evidence. Coupled with some early efforts at using computer simulations to interpret the archaeological record (e.g. Chadwick, 1978; Effland, 1979), a foundation was established for the ongoing development of a digital archaeology.

H.J. Pomerantz (1981) introduced one of the earliest conceptualizations of a Geographical Information System (GIS) specifically designed for archaeological interpretation. Building on this methodological cornerstone, several researchers continued to develop this approach and expand its range of application. H. D. Blaine and J. R. Davis (1984) developed an archaeological site potential map of Australia, while T. E. Davidson (1986) applied digital techniques for modifying historical maps as a means of archaeological interpretation. Kenneth Kvamme and Michael Jochim (1989) used GIS to identify an environmental basis for Mesolithic settlement patterns in southern Germany and D. L. Carmichael (1990) used GIS to determine site distribution patterns in central Montana.

E. D. Hunt (1992) employed GIS to improve site catchment analysis as a way of mapping settlement patterns among horticulturalists of northeastern North America. V. Gaffney and Z. Stancic (1994) used GIS to study the historical archaeology of the Island of Hvar in Croatia, and M. W. Lake *et al* (1998) applied GIS to viewshed analysis and P. Spikins *et al* (2002) examined the different occupation phases of early prehistoric sites in West Yorkshire using a GIS approach. More recently J. D. Nigro *et* *al* (2003) plotted the distribution of fossil finds in Swartkrans, South Africa, and R. Fyfe (2006) explored patterns of pollen deposition and distribution in southwest England using GIS.

As the above studies attest, the application of GIS to archaeological research problems has become increasingly sophisticated over the last twenty-five years and has taken its place as a leading-edge technique in the spatial analysis of archaeological data. The distribution of materials in the archaeological record has long fascinated researchers and one of their ongoing quests has been for increasingly precise, and thus informative, ways of interpreting these spatial patterns. Since such patterns are the remnants of past processes, it is absolutely essential that their natures be understood as clearly as possible if we are to have any hope of reconstructing even a fragment of past lifeways. This fundamental concern of anthropological archaeologists is a natural fit with GIS analysis and its use within the discipline continues to accelerate at rapid pace.

Archaeological GIS analyses, as described above, have included attempts to determine how occupation sites and natural resources were distributed across a given archaeological landscape to further our understanding of the relationship between the two; efforts to assess the nature of population movements and resource exploitation, and how this changed over time; and reconstructions of the natural prehistoric landscape to more fully contextualize a particular archaeological record and its constituent elements. These and other areas of traditional archaeological research are being revisited with increasing frequency as the considerable promise of GIS analysis continues to be realized.

In a rare example of GIS analysis being applied to specific lithic artifact attributes Thomas J. Minichillo (2005), as part of his doctoral dissertation, examined edge damage patterns across an entire assemblage of Middle Stone Age points from Mossel Bay, South Africa. He assessed the distribution of various forms of edge damage along the perimeters of these tools in an effort to identify any patterning as a function of either natural or cultural agency and found that observed edge damage on quartzite points was cultural in origin (ibid, 2005: 211-212). The present study represents a further expansion of the versatility of GIS analysis as applied to lithic technology. It differs from most other GIS-based archaeological analyses in that instead of focusing on macro-level spatial patterning, such as the locations of exploitable resources within a given region, it considers the surface of individual stone tools at high magnification as a different kind of archaeological landscape. By doing so it permits measurement of subtle differences in surface characteristics between worn and unaffected areas of the tool's interior surface and any changes therein over time.

GIS analysis therefore allows evaluation of changes in these characteristics during the course of tool use. This augments the measurement of wear invasiveness through digital image analysis by determining rates of reduction in microtopographic relief at a high degree of resolution due to progressive wear accrual. Before describing the procedures developed for the present study, a brief review of those of some previous investigations into tool surface roughness as an indicator of use mode will be provided to contextualize the GIS approach in terms of the evolution of use-wear methodology.

Methodology

Along with several other traditional wear attributes, surface roughness has often been the focus of efforts to improve the quantification of wear patterns and therefore our ability to differentiate between them. A reliable means of associating a certain combination of wear characteristics with a particular subsistence-related activity has proven to be something of an analytical holy grail for use-wear researchers. In the pursuit of this elusory goal, considerable insight and ingenuity have been brought to bear over the last two decades. Albeit relatively infrequently, as far back as the mid-1980s use-wear analysts devised experiments geared toward documenting variations in tool surface microtopography as a way of associating observed characteristics with the activities responsible for their generation.

Although analyses of wear traces at high magnification have been carried out since at least the late 1970s (e.g. Diamond, 1979; Kamminga, 1979; Keeley, 1977), efforts geared specifically towards their quantification were not made until the early to mid-1980s (e.g. Dumont, 1982; Grace, Graham and Newcomer, 1985; Mansur-Franchomme, 1983.) Rolf Bauche (1986) tackled the problem of documenting use-related changes in tool surface roughness on non-flint lithic raw materials by employing what he referred to as the *profile method.* Using a needle-tipped electronic perthometer, several lines were traced across a given tool surface and its microtopography recorded in terms of the vertical distance traversed by the needle in response to changes in micro-elevation. All lines recorded for the tool were then assembled to produce a rendering of the tool surface as a whole. While certainly innovative for its time, Bauche himself acknowledged that the measurements recorded are in part a function of needle form and its resulting interaction with a markedly irregular tool surface (ibid: 51). Despite this he was still able to approximate tool surface roughness in a fairly systematic manner.

Almost ten years later Kimball, Kimball and Allen (1995) re-visited the problem of measuring roughness of use-related wear polishes using an atomic force microscope. At the time they published their study SEM analysis of wear traces already had a fairly extensive history within the discipline but was still considered to be largely qualitative in nature (ibid: 9). As an alternative, Kimball *et al* turned to atomic force microscopy to view selected areas of tool surfaces following different kinds of subsistence-related use. They conducted the same kind of experiments Keeley (1980) did to evaluate the utility of surface roughness measurements as a way of more reliably distinguishing between the different wear traces they generated. Comparing scans of their experimental tools prior to and following use they were able to document quantifiable differences between wear traces associated with working antler, wood, dry hide and meat. Kimball's *et al* results are compelling but their approach provides data on average roughness rather than specific data on changes in microtopography across the surface of a tool and over time.

Stemp and Stemp (2003) introduced UBM laser profilometry to the problem of quantifying such changes in the microtopographic variability of stone tool surfaces. They used fractal geometry to characterize surface attributes as a basis for evaluating the nature of wear development on a set of experimental flint tools. Stemp and Stemp, like Kimball *et al* (1995) and Bauche (1986), chose to assess entire sections of tool surfaces, which can be a time consuming proposition. The GIS-based approach presented here can be used to efficiently generate representative profiles of tool surfaces increasing the feasibility of evaluating larger numbers of tools and several stages of use for each specimen.

Again like their predecessors, one issue Stemp and Stemp acknowledge as being fundamental yet beyond the scope of their study is the role of raw material variability in the process of wear development. The ability to directly assess microtopographic variability across a tool's surface and how it changes during use is essential for greater understanding of the ways in which the properties of a given raw material influence the rate of wear accrual. Recognition of these effects has profound implications for the interpretation of archaeological wear traces in terms of both tool function and use intensity. Reliable inferences regarding the nature of tool use in all its aspects is foundational to any detailed reconstruction of prehistoric subsistence strategies, thus the formulation and testing of effective methodologies are of paramount importance.

During the course of the digital image analysis it became apparent that the ClemexVision software was not particularly well suited to high-resolution quantification of wear accrual patterns in all three dimensions. It was then decided to employ GIS analysis for a practical and effective solution that would complement the results obtained using the Clemex system. Since two of author's research assistants were already very familiar with the program, the Idrisi Kilimanjaro GIS software package was selected for use in the present study. The Clemex system shed considerable light on how raw material can influence rates of wear accrual in the form of invasiveness measures that evaluate both edge and interior surface modification. What it does not readily assess is how homogeneous the wear is from one raw material and one experimental stage to the next. Idrisi, and GIS in general, offers a detailed and systematic way of assessing this homogeneity in terms of how wear develops on various aspects of a tool's surface microtopography. GIS analysis thus compliments the kind of results obtainable through digital image analysis so that together they are able to provide a more complete picture of wear accrual rates as a function of raw material.

The original SEM images were imported into the Idrisi software and converted to the Idrisi raster-based format to enable further analysis (*Figure 6.1*). SEM images are the cumulative product of single-point readings of secondary electron emissions taken across an entire sample surface one transect at a time. These emissions are recorded as flashes of light emitted by the secondary electrons in response to a scintillation material housed in an electron detector. The intensity of these flashes is directly proportional to the number of secondary electrons emitted by the sample at each measured point. Each pixel in the resulting black and white image therefore represents a single flash or reading and its particular shade of gray reflects the intensity of that flash. The Idrisi program assigns numerical values to each shade of gray such that for a given sample of pixels a set of data can be produced that depicts the degree of microtopographic variability for the portion of tool surface represented by the sample and thus any progressive modification it may exhibit due to the accumulation of wear.

It is important to recognize that the data generated by Idrisi does not depict actual surface microtopography but rather an exaggerated form of it that greatly facilitates identification of worn relative to unworn surface areas and any changes within and between the two. Once the SEM images were converted to raster format, different areas on the tool surface were isolated (*Figure 6.2*) for recording a pixel transect. Three one-pixel wide and approximately 500-pixel long transects were recorded across each tool surface from the working edge towards the centre (*Figure 6.3*). These transects were distributed as evenly as possible along the length of each tool in order to obtain a representative sample of data. Given that wear does not develop evenly along a given length of tool edge, it is necessary to document a number of transects to serve as a basis for subsequent generation of representative mean values. The drawing or digitizing of these transects records the resulting data in vector format. These data were then converted back to raster format (*Figures 6.4* and *6.5*) to enable calculation of individual gray values.

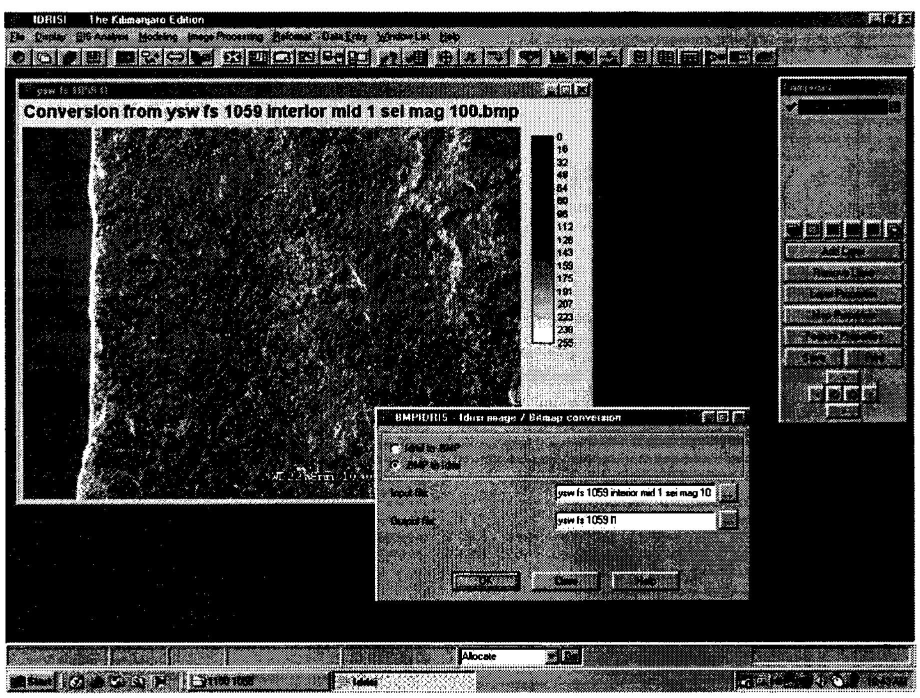


Figure 6.1: An SEM image after it has been imported into and converted by Idrisi.

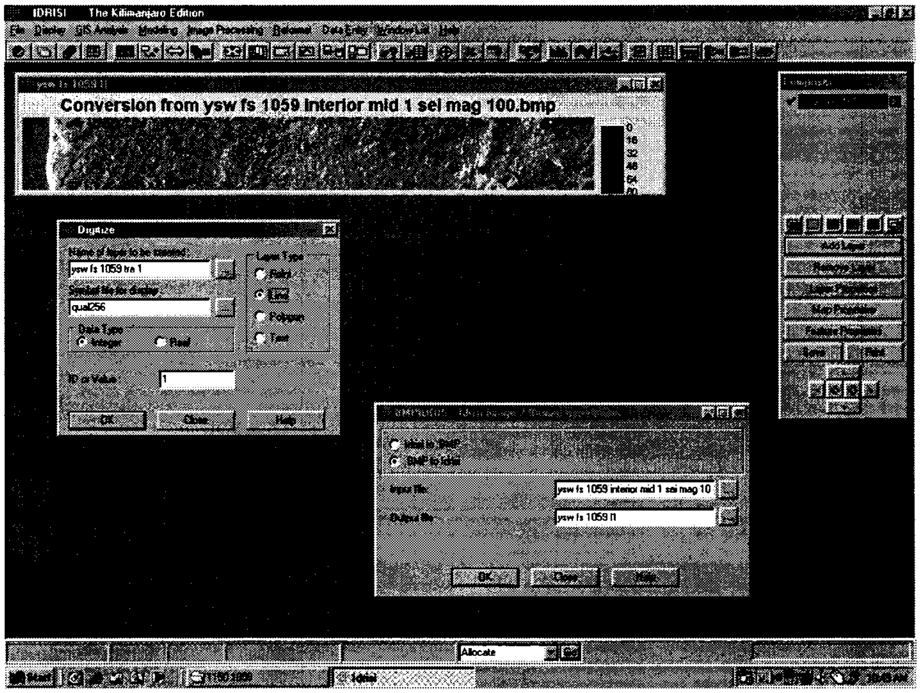


Figure 6.2: Zooming into a specific area of the tool surface in preparation for recording a transect.

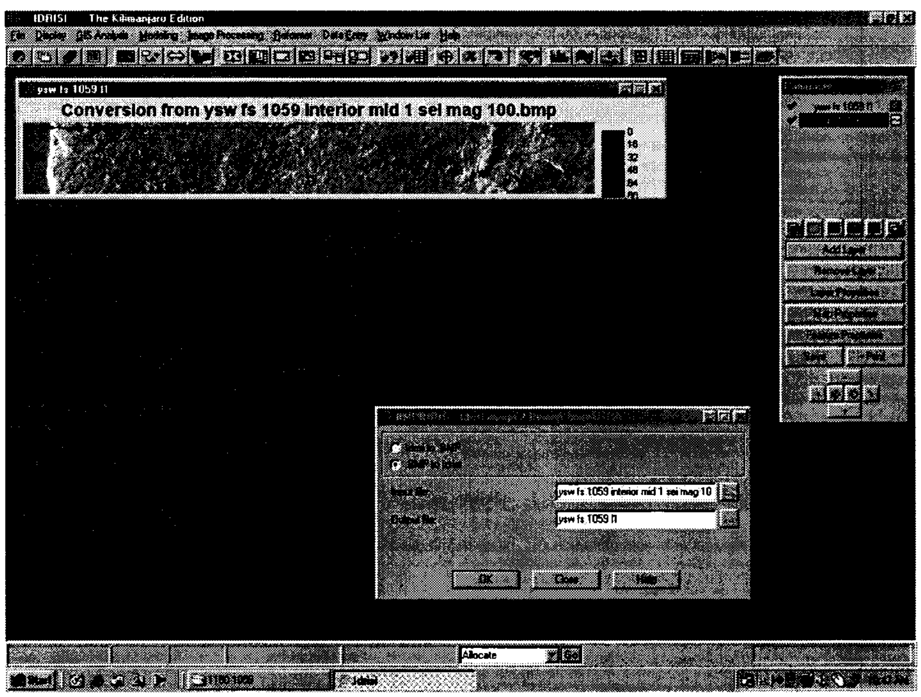


Figure 6.3: Recording a single transect one pixel wide and about 500 pixels long.

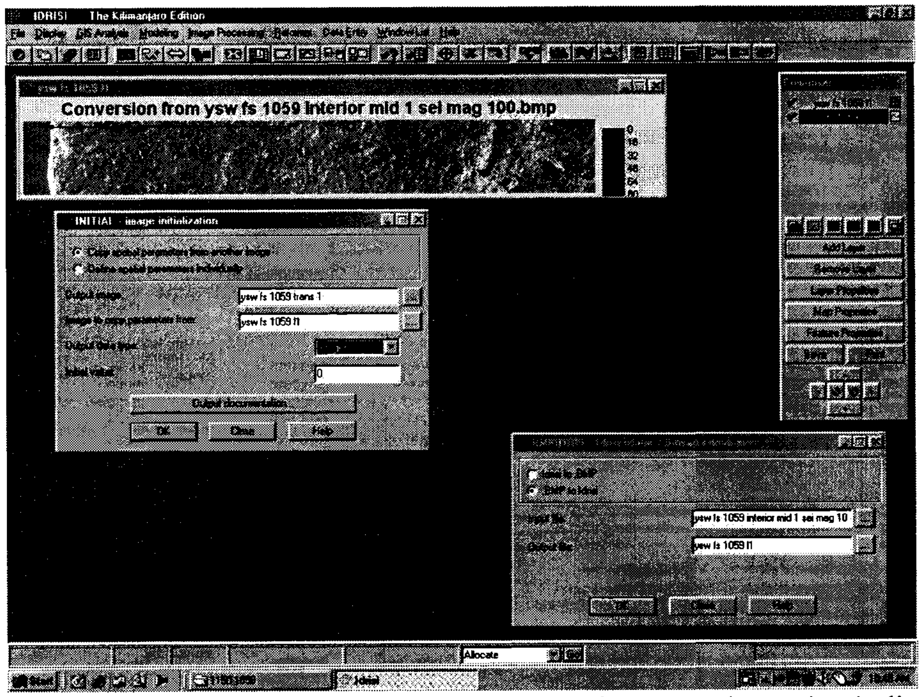


Figure 6.4: Conversion of a transect back to raster format to determine individual gray values.

One final conversion back to vector format was required to facilitate data analysis. The data were then exported to a text file that in turn was imported into Microsoft Excel to

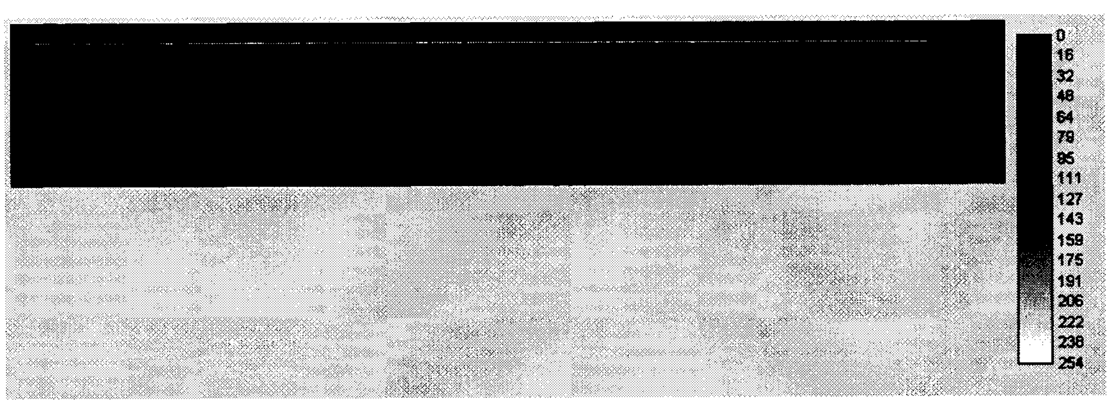


Figure 6.5: The resulting transect in raster format and the scale of recorded gray values.

produce a spreadsheet for each transect. Once the data were brought into Excel, line graphs were generated that represent the microtopography along each transect in exaggerated form.

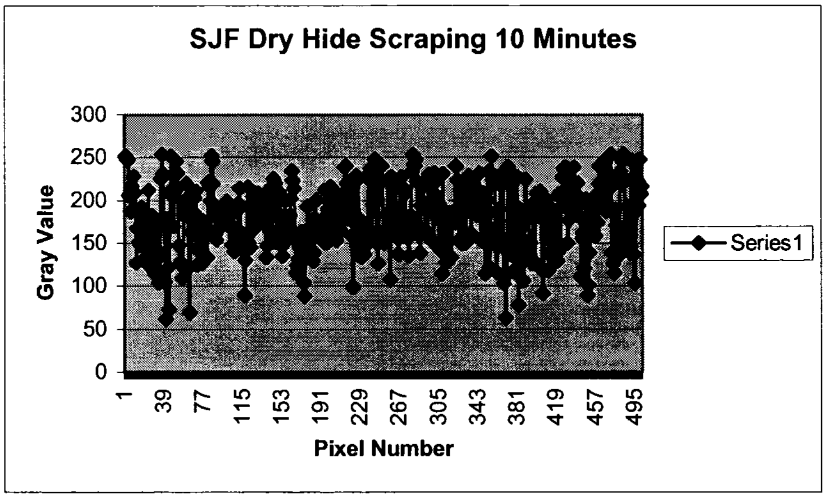
These graphs allowed for systematic distinctions to be made between worn and unworn areas along each transect. With these distinctions made, the mean gray value and standard deviation for each area of each transect were determined. This served as a basis for calculating mean coefficients of variation as a way of quantifying differences in homogeneity of wear accrual over time as a function of activity type and raw material.

In addition to facilitating far more objective quantification of use-wear homogeneity, another advantage of analyzing the SEM images on a pixel-by-pixel basis using GIS is that it permits evaluation of use-wear even if organic residues continue adhere to the tool surface after cleansing is complete. Since the GIS software interprets the images as a collection of pixels each with its own numerical gray value, it is a fairly straightforward matter to exclude those pixels associated with organic deposits from further analysis. These pixels are represented on the initial line graphs as pronounced outliers with uncharacteristically low gray values compared to those comprising the remainder of the given transect, i.e. they appear very dark or even black on the original SEM image. It is also important to note that in assessing wear homogeneity pixel gray values associated with all forms of edge modification, i.e. rounding and/or micro-fracturing, were excluded from analysis to ensure that all gray values considered were directly associated with the same form of wear accrual. In other words, a rounded or curved edge will exhibit a different range of gray values due to its curvature and thus variable orientation relative to the electron beam during scanning with the SEM. In the case of microfracturing, the outer-most portion of the tool surface directly adjacent to the tool edge is lost along with any use-wear evidence that may have accrued in that area up to that point. This effectively resets the tool surface back to zero in terms of the amount of measurable wear. Although not part of the present study, the analysis of edge rounding and microfracturing using GIS holds considerable potential for furthering our understanding of patterns of wear accrual and the role raw material variability plays in this process.

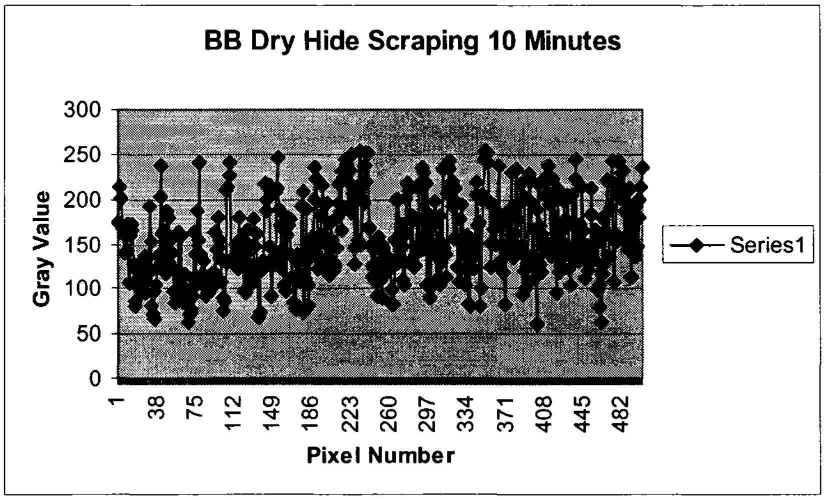
Results

The line graphs and the pixel gray values they represent were generated for each tool after each stage of the experiments and for the sample of ten archaeological flake tools from FA2-13. Figures 6.6 through 6.8 illustrate line graphs for the first set of experimental dry hide scraping tools. The higher gray values observable on the far left-hand side of several of these graphs are associated with either edge rounding or microfracturing and are therefore excluded from subsequent analysis.

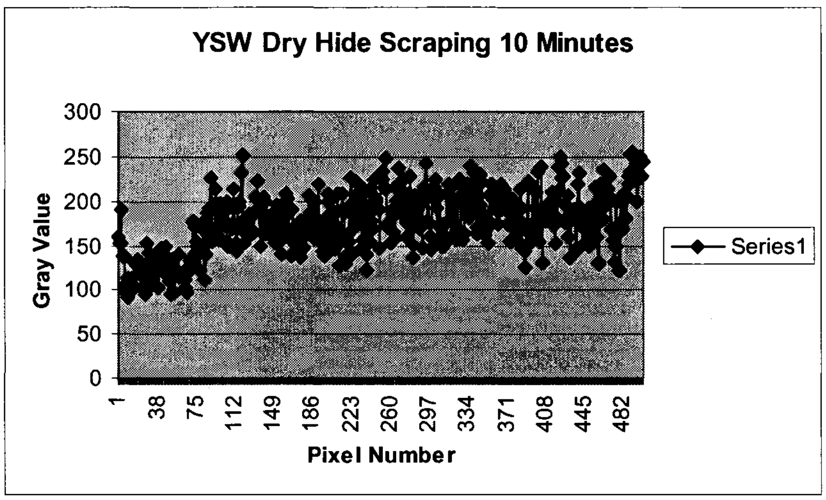
Figure 6.6: Line graphs of pixel gray value for 10 minutes of scraping dry hide.



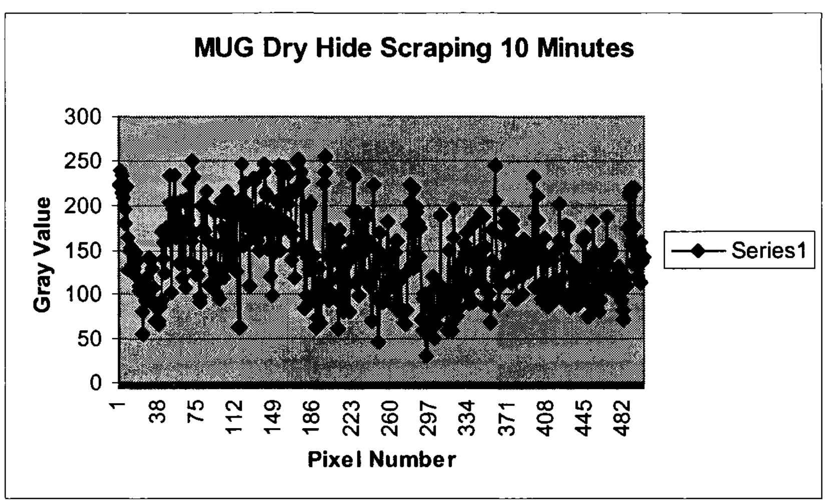
a


BB Dry Hide Scraping 10 Minutes
Gray Value
300
250
200
150
100
50
0
1
38
75
112
149
186
223
260
297
334
371
408
445
482
Pixel Number
Series1

b

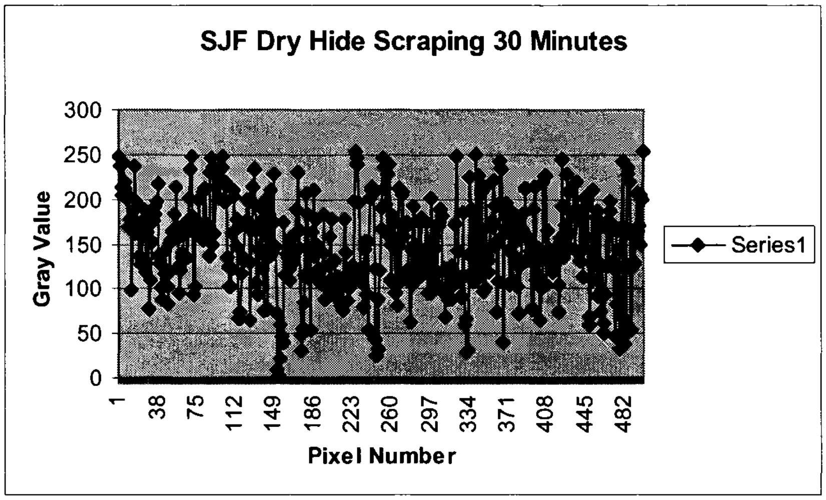

YSW Dry Hide Scraping 10 Minutes
Gray Value
300
250
200
150
100
50
0
1
38
75
112
149
186
223
260
297
334
371
408
445
482
Pixel Number
Series1

c

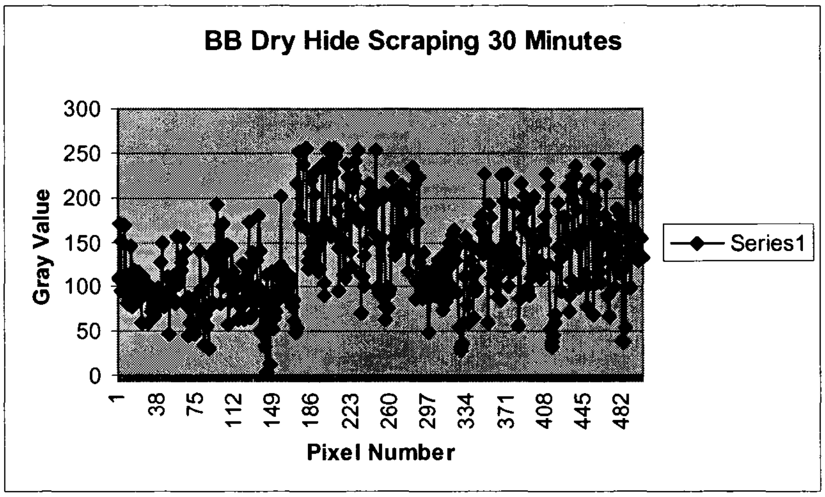

MUG Dry Hide Scraping 10 Minutes
Gray Value
300
250
200
150
100
50
0
1
38
75
112
149
186
223
260
297
334
371
408
445
482
Pixel Number
Series1

d

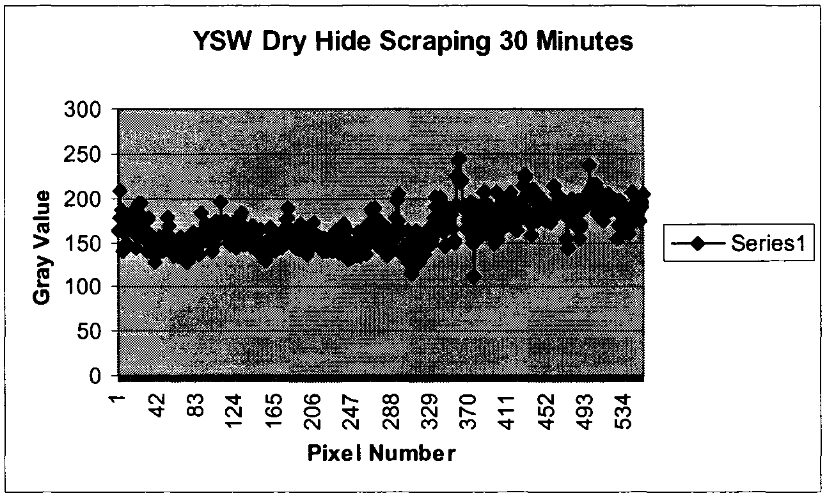
Figure 6.7: Line graphs of pixel gray value for 30 minutes of scraping dry hide.



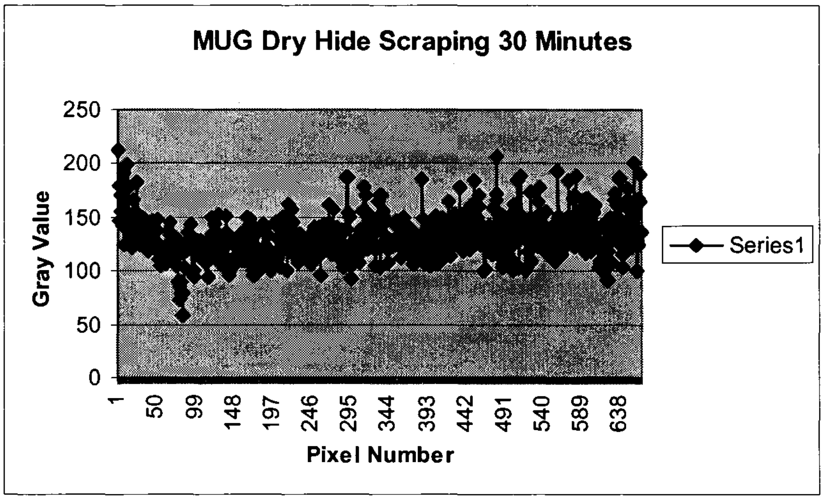
a



b

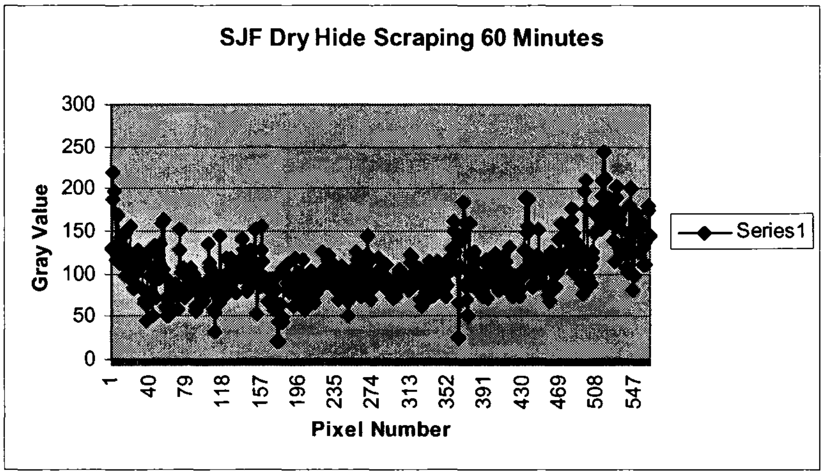


c



d

Figure 6.8: Line graphs of pixel gray value for 60 minutes of scraping dry hide.



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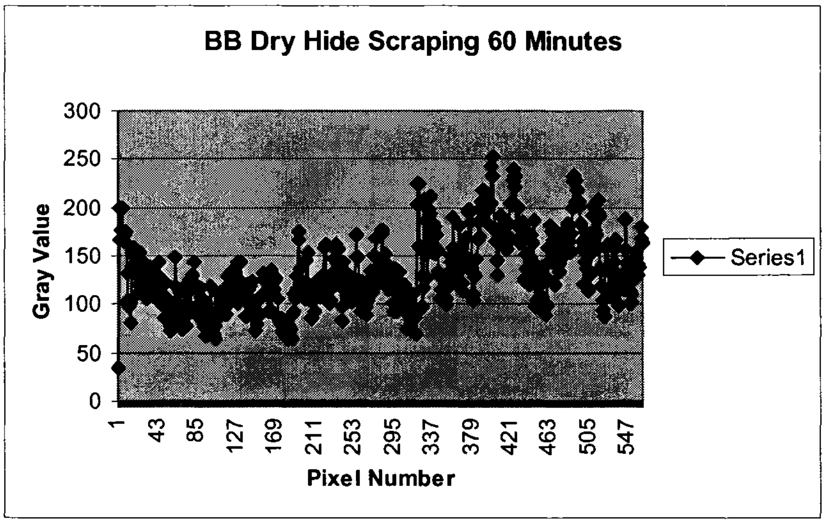
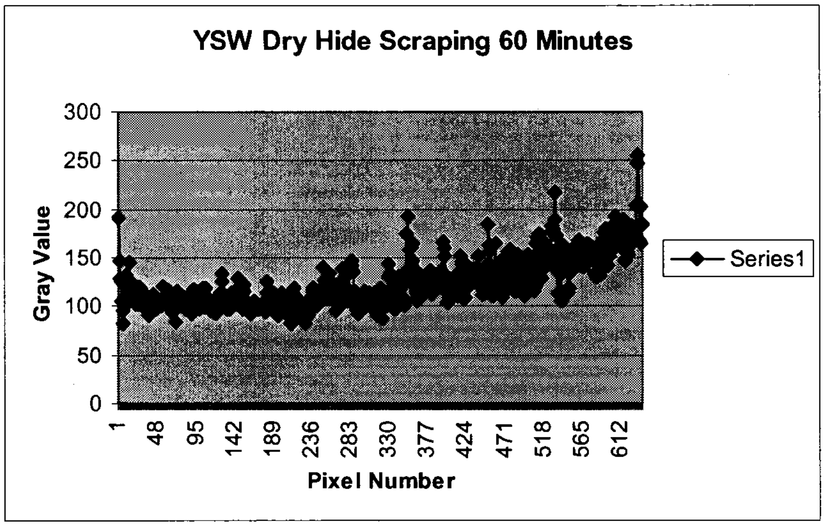
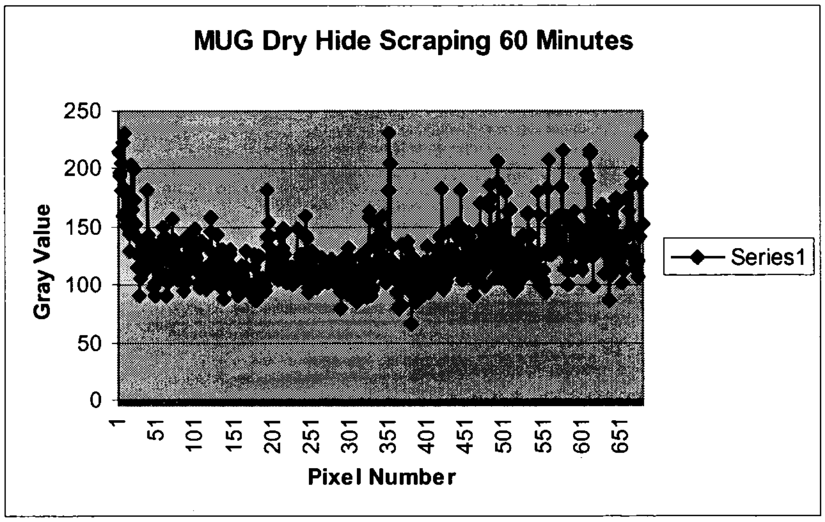


b

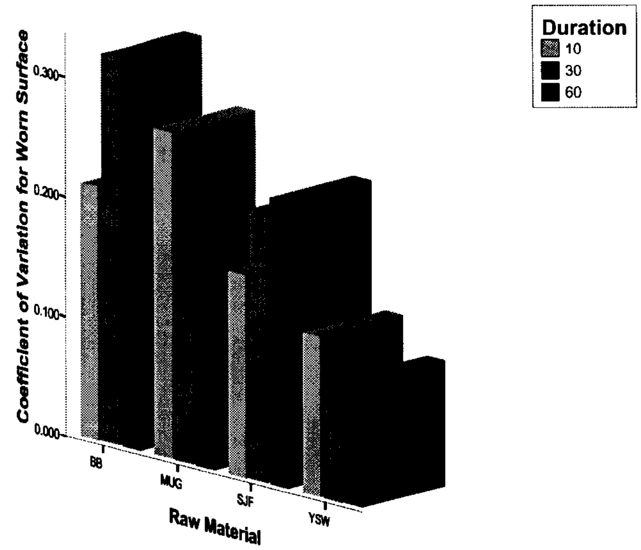


c



d

As already mentioned, coefficients of variation were calculated for both the worn and unworn segments of each pixel transect on each image. This was done in a preliminary effort to further quantify use-wear homogeneity. Figures 6.9 through 6.13 are bar graphs of mean coefficient values for the first and second sets of dry hide scraping tools, the fresh hide scraping tools and the juniper wood planing tools respectively.



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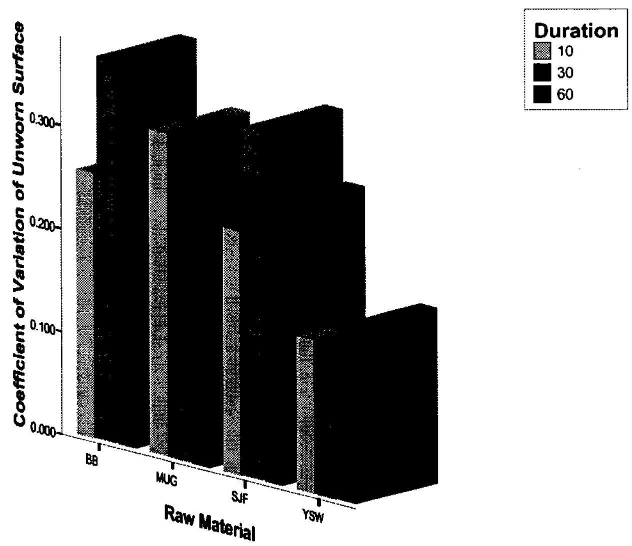
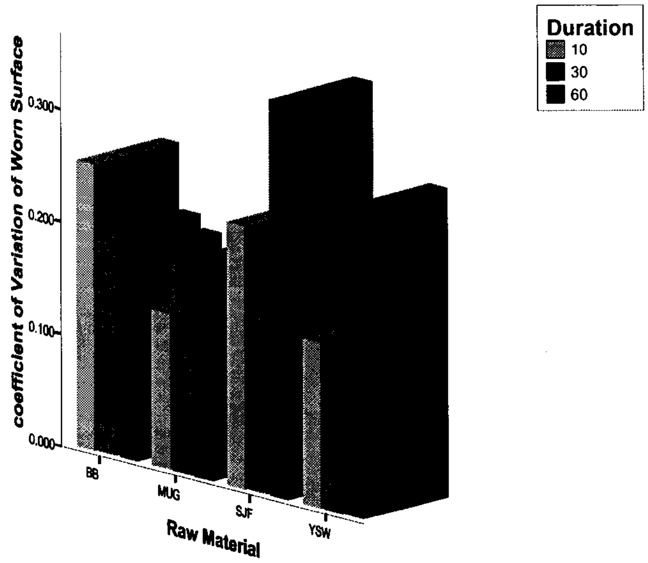
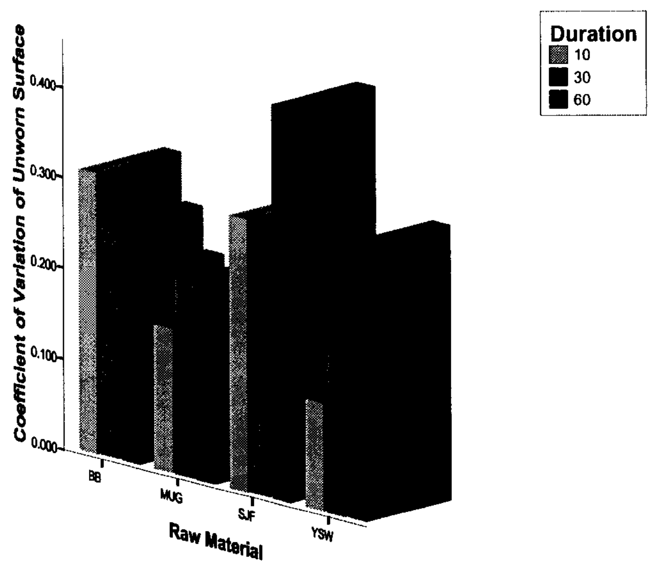


b

Figure 6.9: Mean Coefficients of Variation for the first set of experimental tools used on dry hide.

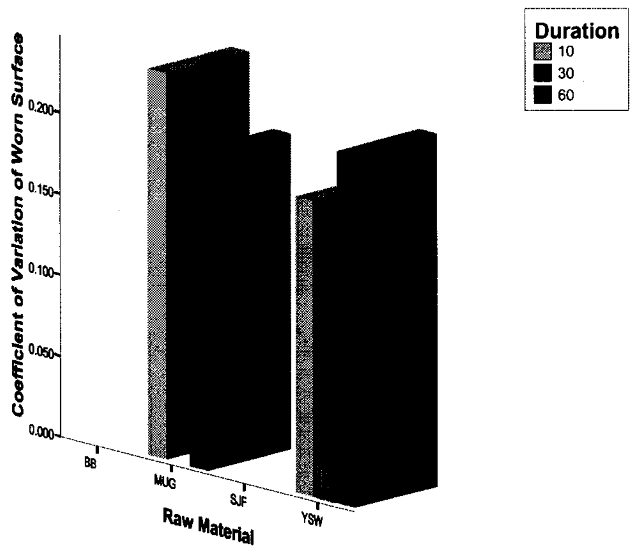


a

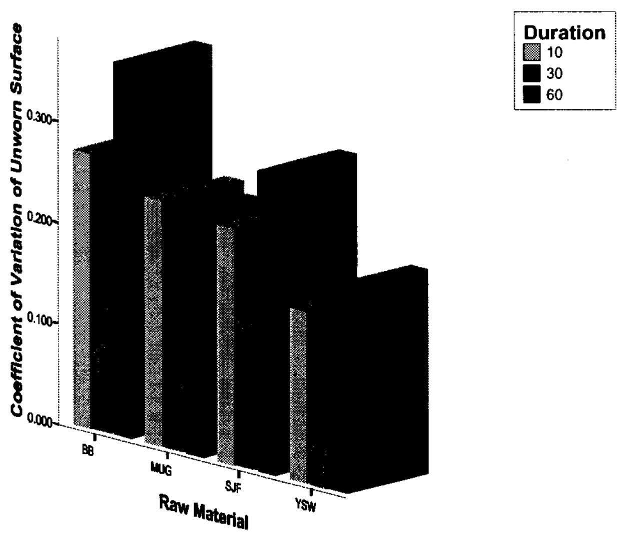


b

Figure 6.10: Mean Coefficients of Variation for the second set of experimental tools used on dry hide.

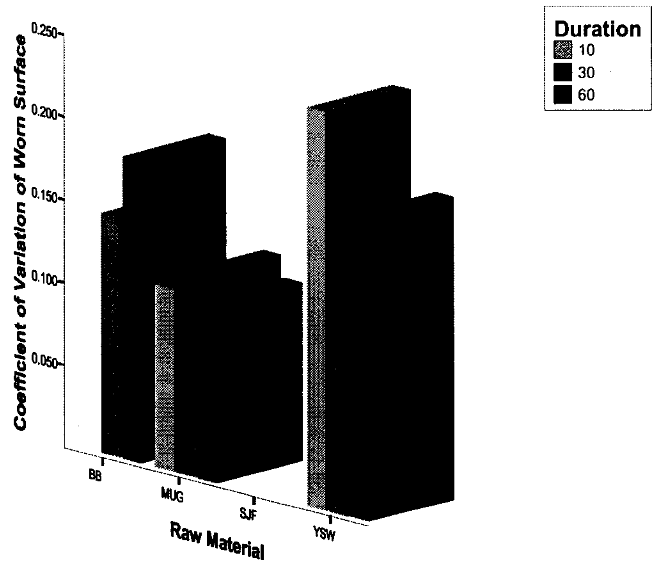


a

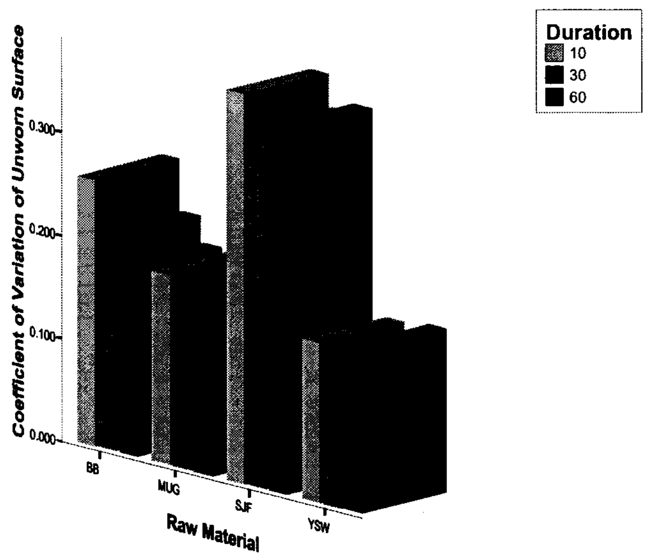


b

Figure 6.11: Mean Coefficients of Variation for the experimental tools used on fresh hide.

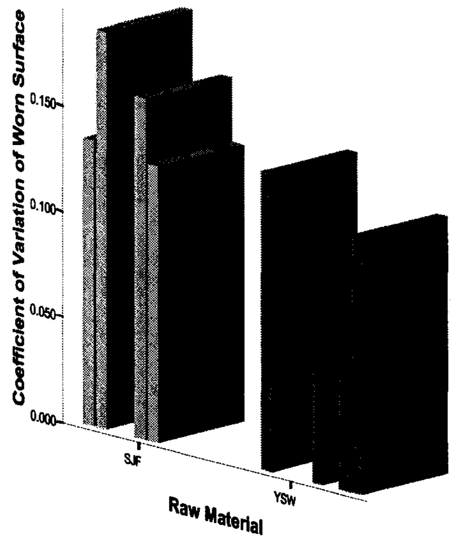


a



b

Figure 6.12: Mean Coefficients of Variation for the experimental tools used on juniper wood.



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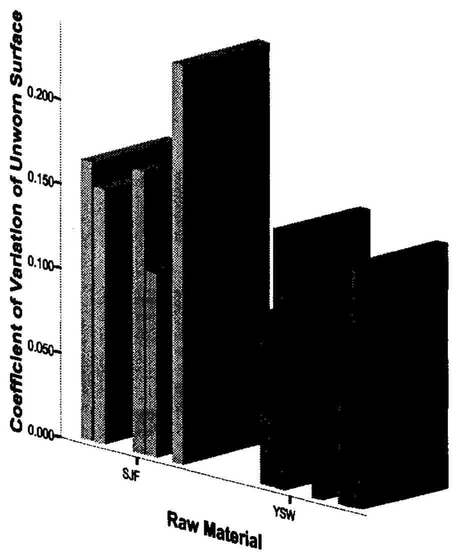


b

Figure 6.13: Mean Coefficients of Variation for the archaeological flake tools from FA2-13.

Through all three stages of the first experiment with scraping dry hide, YSW exhibited the most homogeneous patterns of wear accrual. MUG, while not accruing much wear after 10 minutes of use, had the next highest degree of homogeneity of wear after both 30 and 60 minutes of use. BB and SJF, in order of decreasing wear homogeneity, accrued wear such that after 10 and 30 minutes of use only the high points of their surface microtopographies were significantly affected. Only after 60 minutes of using each of these materials did wear begin to cover a greater proportion of the overall tool surface.

In the majority of cases use-wear became increasingly invasive the more a tool was used. At the same time, the range of gray values across the worn area of each tool decreased, consequently appearing on the line graphs as greater concentrations of points within a narrower range of values. This trend is most evident among the YSW experimental tools. While homogeneity of wear is greatest for YSW, it is also important to recognize that this material had the most narrow range of gray values to begin with, as evidenced by the unworn areas of these tools' surfaces along each transect. The issue of inherent microtopographic variability or surface roughness will be addressed in greater detail in the next chapter.

Similar trends in terms of increasing homogeneity of use-wear were observed for both scraping fresh hide and planing juniper wood, albeit in relatively less pronounced forms. Scraping fresh hide (for line graphs see *Figures B.1* to *B.12*) overall generated less pronounced use-wear than did scraping dry hide, but the differences in rates of wear accrual from one raw material to the next were analogous to those for dry hide. YSW again accrued wear most rapidly, but in this case the tool edge was very thin to begin with and collapsed during the first stage of the experiment resulting in the production of microfractures. The higher and more variable gray values at the far left-hand side of each line graph are thus associated with these microfractures.

As with scraping dry hide, YSW also exhibited the highest degree of use-wear homogeneity despite being truncated by microfractures, a form of use-wear that also requires further study in the future. Where the pattern differs is that as use-wear invasiveness increases, its homogeneity actually decreases. This is a result of use-wear being restricted to the highpoints of the tool's surface microtopography as opposed to affecting the tool surface as a whole, as was the case for working dry hide. As a result, the wear that did accrue actually contributed to overall surface irregularity and thus gray value variability. With continued use it is likely that use-wear would accrue on a large enough percentage of the tool's microtopography, as it did with scraping dry hide, to effectively decrease surface irregularity and pixel gray value variability. While an intuitively logical extrapolation of current results, this still needs to be empirically demonstrated through further experimentation.

MUG was the only other material to exhibit invasive use-wear; although during the second stage of the experiment this tool also experienced edge failure resulting in the loss of all wear evidence accrued during the first stage of the experiment. Comparing the results after the first and third stages of the experiment, MUG exhibited the reverse pattern of wear homogeneity as YSW, that is use-wear homogeneity was greater after 60 minutes than after 10 minutes of use. However, since edge collapse during the second stage of the experiment effectively reset tool surface microtopography back to a natural state a trend in terms of use-wear homogeneity for planing juniper wood cannot be established without further experimentation. Both BB and SJF did not accrue any invasive wear, only exhibiting slight edge rounding with SJF developing the least amount of wear of any of the materials under consideration.

Thus 60 minutes of scraping fresh hide had no appreciable effect on the surface microtopographic variability of either of these two cherts.

Planing juniper wood (for line graphs see *Figures B.13* to *B.24*) yielded rates of use-wear accrual analogous to those of the other two activities. YSW again accrued wear most readily with edge modification being exclusively in the form of microfractures. Invasive surface wear occurred both within the microfracture scars and beyond the maximum extent of their invasiveness. YSW exhibited the highest degree of use-wear homogeneity after 30 minutes, but was initially more variable than MUG after 10 minutes of use and decreased again after 60 minutes of use. Working materials like fresh hide and wood tends to generate use-wear more gradually thus affects different portions of tool surface microtopography at different rates. Working dry hide generates wear more evenly, resulting in more uniform *micro-reduction* of a tool's edge and surface, as illustrated by a steady increase in use-wear homogeneity.

MUG exhibited the reverse of the pattern observed for YSW. After 10 and 60 minutes it had the highest degree of wear homogeneity and after 30 minutes of use the second lowest values for this measure. BB and SJF again were the least affected raw materials. While SJF did not accrue any invasive use-wear, only some slight edge attrition after 60 minutes of use, BB did accrue such wear after 30 minutes, which developed significantly after 60 minutes of use. BB displayed a noticeable increase in use-wear homogeneity after 60 minutes of use.

The second set of experimental dry hide scraping tools exhibited patterns of wear homogeneity similar to those of the first set (for line graphs see *Figures B.25* to *B.36*). YSW exhibited the highest degree of use-wear homogeneity through the first two stages of the experiment. Unlike with the first set of tools, however, after 60 minutes of use the coefficient of variation for YSW was actually the second highest of the four materials The collapse of the tool edge during this stage of the experiment, as discussed in the previous chapter, removed the most highly developed or homogeneous portion of the use-wear generated through the first 30 minutes of use, affecting a net decrease in use-wear homogeneity. MUG exhibited the second highest degree of use-wear homogeneity followed in decreasing order by BB and SJF.

As with the digital image analysis, the same sample of 10 archaeological flake tools from FA2-13 was assessed using GIS (*Figure 6.13*; for line graphs see *Figures B.37* to *B.46*). The YSW tools consistently exhibited lower coefficients of variation, thus higher degrees of use-wear homogeneity compared to the SJF tools. This compares well with the Clemex results as the YSW tools displayed more invasive and uniform use-wear patterns than did their SJF counterparts. Comparing these findings with the experimental results may indicate that the YSW tools with the most homogeneous wear were used to scrape dry hide and those with relatively less homogeneity of wear to scrape fresh hide. It is also possible to infer that the SJF tools were used either to work materials that generate use-wear more gradually or were simply used with lesser intensity. While these are all plausible interpretations, one has to be aware of the effects of both raw material variability and use duration on the nature of wear accrual and factor these effects into any interpretation. Tables 6.1 to 6.5 present the coefficient of variation data for the first and second sets of dry hide scraping tools, the fresh hide scraping tools, the juniper wood scraping tools and the archaeological flake tools from FA2-13 respectively.

Discussion

The results of the GIS analyses proved corroborative to those of the preceding chapter. As established by the ClemexVision digital image analysis, YSW accrued wear most readily of any of the four raw materials under consideration. While use-wear was consistently most invasive for YSW, the homogeneity of these traces presented a different but complimentary pattern. Invasiveness of use-wear was, in most cases, progressive from one stage of the experiment to the next, but homogeneity of use-wear tended to develop differently. Scraping dry hide did tend to yield a progressive increase in homogeneity, but the other activities often resulted in initial increases followed by subsequent decreases in use-wear homogeneity.

Invasive use-wear does not automatically imply a high degree of homogeneity. Use-wear can be observed some distance away from the utilized edge while still being restricted to the high points of a tool's surface microtopography. In such a case, although observable use-wear is quite invasive its homogeneity is relatively low and would likely yield higher coefficients of variation. It is worth re-iterating at this point that the GIS-based line graphs of the distribution of pixel gray values are amplified representations of tool surface microtopography. This amplification allows for clearer differentiation between worn and unworn areas on a pixel-by-pixel basis. This, in turn, facilitates the identification of any patterning of wear accrual as a function of raw material, activity and/or use duration.

The increases in the coefficients of variability for YSW between 30 and 60 minutes of scraping fresh hide, for example, do not run counter to the fact that YSW exhibited the most invasive use-wear. On the contrary, they indicate that while wear did indeed become more invasive during the latter stages of the experiment compared to any of the other raw materials, it was also increasingly restricted to microtopographic peaks towards the leading edge of wear. Thus, experimentally it was shown that use-wear develops more gradually and less homogeneously when scraping fresh hide that it does when scraping dry hide. As a result, these increases in the coefficients of variation can be seen as being related to the increases in the overall invasiveness of the use-wear traces. The same relationship appears to generally hold true for planing juniper wood as well, although use-wear seems to accrue even more gradually and less homogeneously than with scraping fresh hide.

While the results of the GIS analysis are quite telling and clearly support those of the digital image analysis, a few qualifications should be kept in mind. As with most archaeological research, sampling is of primary importance. As a preliminary test of the usefulness of GIS in further systematizing use-wear analysis, particularly as it relates to raw material variability, a sample of three randomly distributed transects of pixels were recorded and analyzed. Additional work incorporating a larger number of transects would therefore allow for even higher resolution assessments of use-wear homogeneity. Also, the way in which pixel size is determined may have some effect on analytical resolution. Smaller pixel sizes would likely result in even more detailed representations of tool surface microtopography.

The inherent irregularity of most tool surfaces also plays a role in how many secondary electrons are emitted and recorded from every point on a tool's surface during scanning with an SEM, thus potentially affecting resulting pixel gray values. Additionally, although sample orientation within the SEM chamber was kept as consistent as possible from one tool to the next, given their irregular shapes the process of securing them in the sample holder required re-positioning a few tools, which may have had some effect on how the tool surface was scanned. Lastly, use-related edge rounding and microfracturing need to be assessed independently from general surface wear, as the changes to surface microtopography they introduce are distinct from regular surface abrasion.

With these qualifications in mind, the GIS analysis of use-wear microtopography on both experimental and archaeological short-term use tools has yielded very useful results that significantly enhance those obtained through digital image analysis. This chapter has also shown that even though GIS is rapidly becoming an indispensable analytical tool for archaeologists, its potential for shedding light on the past has only begun to be realized. Chapter Seven examines the inherent physical properties of the four raw materials in question as a way of further explicating the patterns identified in Chapters Five and Six.

Raw Material	Transect	Duration	Worn Surface	Unworn Surface
SJF	1	10	0.173	0.235
SJF	2	10	0.133	0.259
SJF	3	10	0.201	0.214
SJF	1	30	0.234	0.354
SJF	2	30	0.22	0.336
SJF	3	30	0.223	0.329
SJF	1	60	0.219	0.293
SJF	2	60	0.261	0.279
SJF	3	60	0.24	0.239
BB	1	10	0.238	0.261
BB	2	10	0.207	0.259
BB	3	10	0.19	0.252
BB	1	30	0.34	0.358
BB	2	30	0.339	0.379
BB	3	30	0.294	0.378
BB	1	60	0.203	0.224
BB	2	60	0.203	0.253
BB	3	60	0.163	0.258
YSW	1	10	0.133	0.153
YSW	2	10	0.131	0.153
YSW	3	10	0.138	0.143
YSW	1	30	0.089	0.122
YSW	2	30	0.067	0.079
YSW	3	30	0.065	0.092
YSW	1	60	0.097	0.167
YSW	2	60	0.125	0.163
YSW	3	60	0.096	0.182
MUG	1	10	0.247	0.322
MUG	2	10	0.299	0.329
MUG	3	10	0.273	0.291
MUG	1	30	0.129	0.15
MUG	2	30	0.112	0.116
MUG	3	30	0.126	0.177
MUG	1	60	0.144	0.206
MUG	2	60	0.119	0.195
MUG	3	60	0.164	0.223

Table 6.1: Coefficients of Variation for the first set of tools used to scrape dry hide.

Raw Material	Transect	Duration	Worn Surface	Unworn Surface
SJF	1	10	0.221	0.289
SJF	2	10	0.262	0.33
SJF	3	10	0.22	0.282
SJF	1	30	0.189	0.254
SJF	2	30	0.166	0.236
SJF	3	30	0.127	0.264
SJF	1	60	0.416	0.439
SJF	2	60	0.288	0.396
SJF	3	60	0.355	0.473
BB	1	10	0.263	0.295
BB	2	10	0.281	0.348
BB	3	10	0.218	0.285
BB	1	30	0.205	0.251
BB	2	30	0.203	0.235
BB	3	30	0.18	0.278
BB	1	60	0.221	0.25
BB	2	60	0.171	0.196
BB	3	60	0.16	0.178
YSW	1	10	0.144	0.131
YSW	2	10	0.139	0.119
YSW	3	10	0.158	0.108
YSW	1	30	0.151	0.194
YSW	2	30	0.15	0.194
YSW	3	30	0.149	0.18
YSW	1	60	0.304	0.282
YSW	2	60	0.26	0.29
YSW	3	60	0.269	0.35
MUG	1	10	0.141	0.174
MUG	2	10	0.158	0.151
MUG	3	10	0.117	0.148
MUG	1	30	0.193	0.212
MUG	2	30	0.166	0.212
MUG	3	30	0.195	0.216
MUG	1	60	0.26	0.134
MUG	2	60	0.145	0.152
MUG	3	60	0.183	0.146

Table 6.2: Coefficients of Variation for the second set of tools used to scrape dry hide.

Raw Material	Transect	Duration	Worn Surface	Unworn Surface
SJF	1	10	0	0.213
SJF	2	10	0	0.230
SJF	3	10	0	0.259
SJF	1	30	0	0.23
SJF	2	30	0	0.204
SJF	3	30	0	0.193
SJF	1	60	0	0.255
SJF	2	60	0	0.329
SJF	3	60	0	0.312
BB	1	10	0	0.217
BB	2	10	0	0.284
BB	3	10	0	0.315
BB	1	30	0	0.265
BB	2	30	0	0.299
BB	3	30	0	0.28
BB	1	60	0	0.333
BB	2	60	0	0.366
BB	3	60	0	0.409
YSW	1	10	0.218	0.181
YSW	2	10	0.147	0.161
YSW	3	10	0.185	0.167
YSW	1	30	0.123	0.156
YSW	2	30	0.137	0.131
YSW	3	30	0.144	0.142
YSW	1	60	0.225	0.21
YSW	2	60	0.206	0.168
YSW	3	60	0.222	0.229
MUG	1	10	0.203	0.261
MUG	2	10	0.252	0.269
MUG	3	10	0.26	0.201
MUG	1	30	0	0.218
MUG	2	30	0	0.231
MUG	3	30	0	0.245
MUG	1	60	0.189	0.195
MUG	2	60	0.182	0.193
MUG	3	60	0.212	0.168

Table 6.3: Coefficients of Variation for the tools used to scrape fresh hide.

Raw Material	Transect	Duration	Worn Surface	Unworn Surface
SJF	1	10	0	0.357
SJF	2	10	0	0.354
SJF	3	10	0	0.423
SJF	1	30	0	0.346
SJF	2	30	0	0.347
SJF	3	30	0	0.343
SJF	1	60	0	0.392
SJF	2	60	0	0.35
SJF	3	60	0	0.322
BB	1	10	0	0.288
BB	2	10	0	0.228
BB	3	10	0	0.256
BB	1	30	0.158	0.23
BB	2	30	0.159	0.221
BB	3	30	0.119	0.172
BB	1	60	0.202	0.179
BB	2	60	0.137	0.199
BB	3	60	0.21	0.171
YSW	1	10	0.266	0.185
YSW	2	10	0.232	0.132
YSW	3	10	0.226	0.148
YSW	1	30	0.112	0.135
YSW	2	30	0.126	0.131
YSW	3	30	0.109	0.154
YSW	1	60	0.175	0.191
YSW	2	60	0.21	0.143
YSW	3	60	0.164	0.142
MUG	1	10	0.101	0.153
MUG	2	10	0.1	0.211
MUG	3	10	0.131	0.187
MUG	1	30	0.144	0.145
MUG	2	30	0.108	0.135
MUG	3	30	0.112	0.133
MUG	1	60	0.114	0.133
MUG	2	60	0.092	0.147
MUG	3	60	0.118	0.145

Table 6.4: Coefficients of Variation for the tools used to plane juniper wood.

Raw Material	Findspot	Transect	Worn Surface	Unworn Surface
SJF	898	1	0.135	0.155
SJF	898	2	0.132	0.15
SJF	898	3	0.139	0.19
SJF	1032	1	0.2	0.133
SJF	1032	2	0.212	0.175
SJF	1032	3	0.151	0.144
SJF	1082	1	0.157	0.167
SJF	1082	2	0.195	0.143
SJF	1082	3	0.131	0.191
SJF	1087	1	0.093	0.103
SJF	1087	2	0.14	0.107
SJF	1087	3	0.159	0.115
SJF	1137	1	0	0.225
SJF	1137	2	0	0.222
SJF	1137	3	0	0.261
YSW	1040	1	0.153	0.11
YSW	1040	2	0.112	0.094
YSW	1040	3	0.158	0.1
YSW	1059	1	0	0.145
YSW	1059	2	0	0.157
YSW	1059	3	0	0.157
YSW	1131	1	0.069	0.064
YSW	1131	2	0.052	0.077
YSW	1131	3	0.064	0.062
YSW	1149	1	0.091	0.089
YSW	1149	2	0.073	0.101
YSW	1149	3	0.056	0.07
YSW	1156	1	0.11	0.172
YSW	1156	2	0.103	0.12
YSW	1156	3	0.152	0.143

Table 6.5: Coefficients of Variation for the archaeological flake tools from FA2-13.

CHAPTER 7: NANOINDENTATION AND THE TESTING OF MATERIAL PROPERTIES

Archaeologists are always searching for analytical methods that will yield detailed and accurate inferences about human adaptations in the past. The use-wear analyses presented in Chapters Five and Six have shown that valuable insight into past technological systems can be readily achieved. They have also demonstrated that such insights have significant implications for future considerations of prehistoric cultural dynamics. These implications will, for example, affect inferences made regarding tool function, activity intensity, patterns of use-related reduction, assemblage variability and the very nature of overall subsistence strategies. However, any reliable interpretation of past technologies and their place in a population's overall adaptation must rest on a solid understanding of the physical properties of technological materials and the ways in which these interact with subsistence resources in the overall context of social and economic systems.

In many archaeological contexts lithic tools are the most abundant, and sometimes the only, source of information about prehistoric technological systems. A highly categorical approach has traditionally been used when extracting data from the products of lithic technology. Lithic materials have most commonly been divided into types that are loosely defined in either geological (Quartz, Chert or Chalcedony) or in functional terms (for example the widespread use of basalt in the production of stone axes and adzes). The resulting tools are then divided into types despite great morphological variability from region to region and within individual sites. The use-wear evidence they often bear is further divided into types according either to visible polishes and striations or to certain causally related types of activities. All these levels of categorization have had a cumulative reductive effect on the cultural information we ultimately glean from these components of material culture.

In this chapter an example of a less categorical and thus more continuous and explicitly quantitative approach is used to further assess the relationship between lithic raw material variability and resulting trace wear evidence. Without a clearer understanding of the physical nature of the material used to produce stone tools any attempt to interpret their function(s) will be haphazard at best. An appreciation for how a given stone will respond to the application of a given load during use is critical for assessing the nature of that use. Because of the internal variability of lithic materials and the idiosyncrasies of the technological process, an individual stone tool can be seen as a unique combination of raw material properties and as the product of its own unique life history.

Since virtually all varieties of lithic raw materials, even those of the highest quality, are typically heterogeneous, it is important to learn how they vary in both composition and structure. Because even the most routine tasks can be performed in any number of unique ways, it is equally important to consider the highly variable nature of use-wear accrual that results from the myriad interactions between raw material and contact material that characterize a particular social and economic context. The testing of raw material properties through micro-indentation can pave the way for more dynamic and less categorical assessments of the complex relationship between stone tools and social systems. In the present study four different lithic raw materials were subjected to micro-indentation hardness testing in order to gauge variability within and between materials and its relationship to wear accrual.

First an overview of the experimental theory behind nanoindentation and the design of the current tests will be provided. Results of the experiments will then be presented, followed by a discussion of their implications for the archaeological use-wear analyses presented in the previous two chapters. Future directions for research on raw material property variability and its implications for lithic archaeology will also be addressed.

Theory and Experimental Design:

Today indentation techniques are widely used to test the surface properties of various materials. Standard experimental techniques began to be developed in the late 19^{th} century and have continued to be refined into very precise methods of measuring material properties. Their theoretical underpinnings were formulated along the same lines as the elastic/plastic theories in the field of material mechanics (Johnson, 1987).

The nature and duration of prehistoric tool use depends on many physical properties, including Young's modulus E and hardness Hc. Values for both these and other measures can readily be obtained from indentation tests. In solid mechanics, Young's modulus is a measure of the stiffness of a given material and is defined as

$$E = \frac{F \cdot L}{A \cdot \Delta L}$$

where L is the equilibrium length of a sample, ΔL is the length change under the applied stress, F is the force applied, and A is the area over which the force is applied and is measured in units of pressure. A higher value for Young's modulus indicates a stiffer and harder material, and lower values a softer more malleable material. It is important to note that hardness is not an intrinsic material property dictated by precise definitions in terms of fundamental units of mass, length and time. A hardness value is the result of a defined measurement procedure that often involves determining resistance to scratching or cutting (Ostoja-Starzewski, pers. comm.).

The following brief introduction to the mechanical methods employed in the present study explains how the hardness values were obtained. The indenter tip, usually made of a very hard material (e.g. diamond), is pressed into the material surface with a pre-specified applied force (*Figure 7.1*). During the test, the force is loaded and unloaded, and then both the force applied and the entry depth of the tip (h) is recorded by an integrated data acquisition system. The recorded data (*Figure 7.2*) can then be used to calculate Young's modulus and the hardness of the material surface.

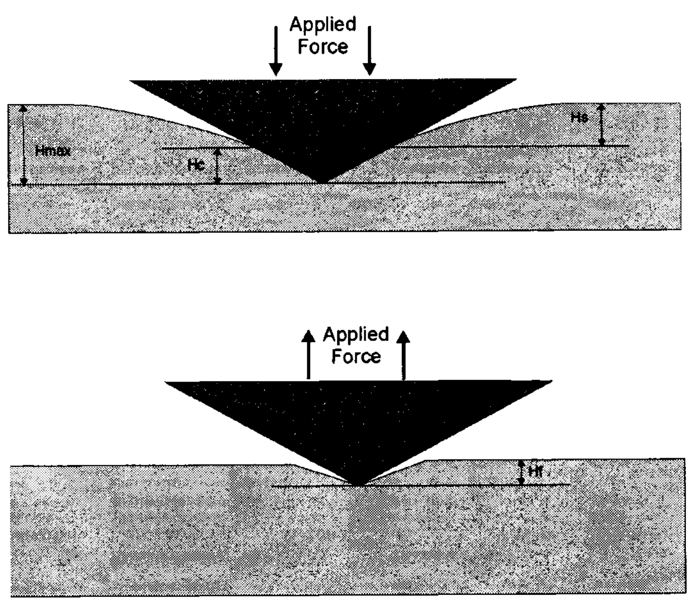


Figure 7.1: Schematic of an indentation test: loading followed by unloading.

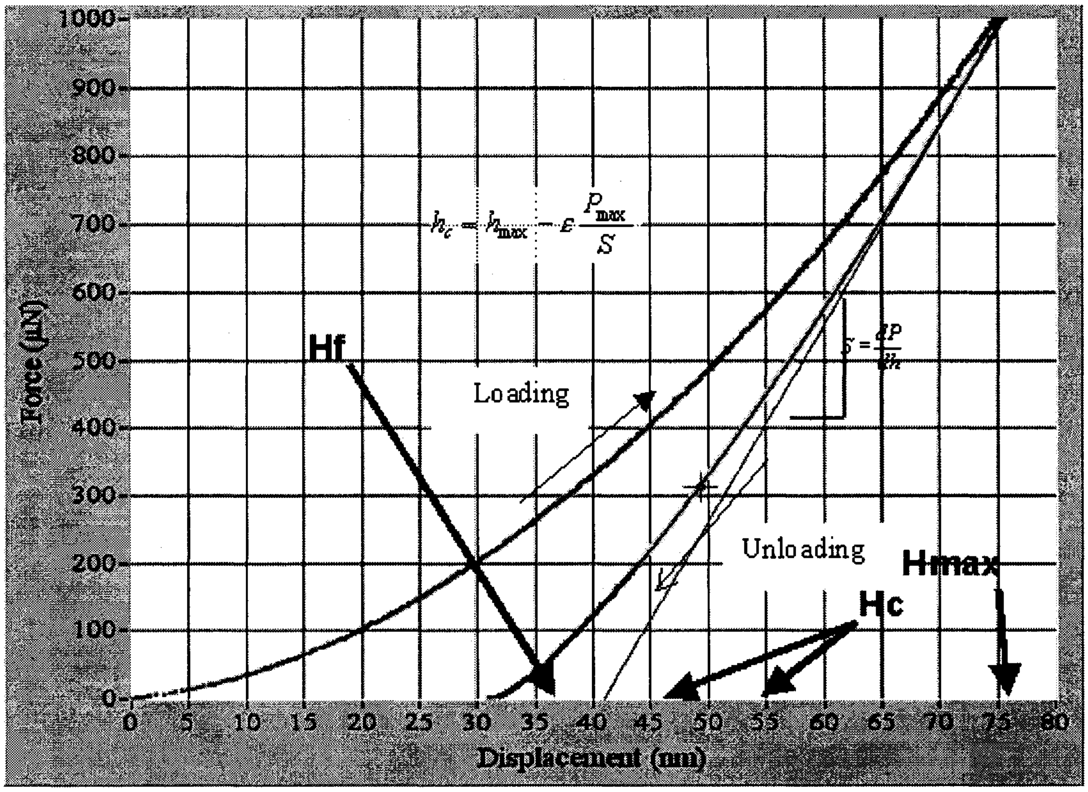
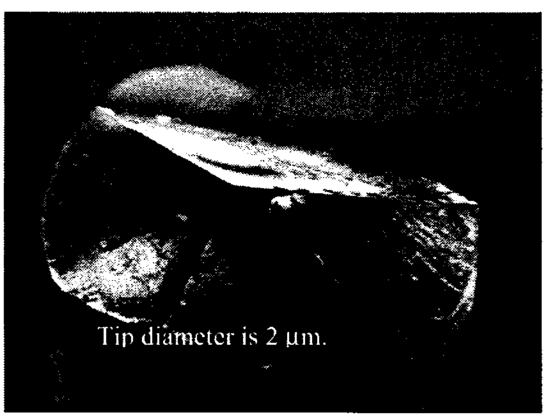


Figure 7.2: A typical loading and unloading process during indentation.

Before proceeding any further it is worth re-iterating that lithic raw materials are almost always heterogeneous or multi-phase in nature, unlike far more homogeneous materials such as steel or aluminium that are the typical subjects of micro-indentation. The influence of microstructures is therefore essential to any understanding of material property variability when dealing with natural, unprocessed materials like stone. The property distribution of particles that characterize stone tool raw material must be tested to fully investigate the nature of trace wear development. Tests must therefore be conducted on a micrometer or smaller scale. Nanoindentation testing is particularly well suited to investigate these properties.

Methodology

A diamond Berkovich tip indenter (*Figure 7.3*) was used in conjunction with a Triboindenter from Hysitron Inc. (*Figure 7.4*) that is specifically designed to conduct highly precise nano-indentation tests to obtain both average values of material properties and their range of variation throughout a given sample. The tip is pressed gradually into the sample with a predetermined load. The loading process lasted five seconds and the maximum load was held constant for another five seconds. The load was then removed gradually over another five-second interval. The entire process for generating a single indentation therefore took a total of 15 seconds (Dr. Martin Ostoja-Starzewski and Xiangdong Du, pers.comm.).



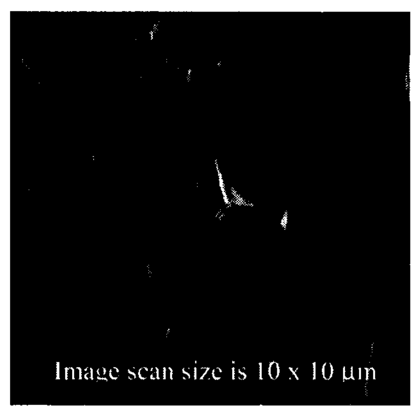


Figure 7.3: The Berkovich tip and resulting indentation.

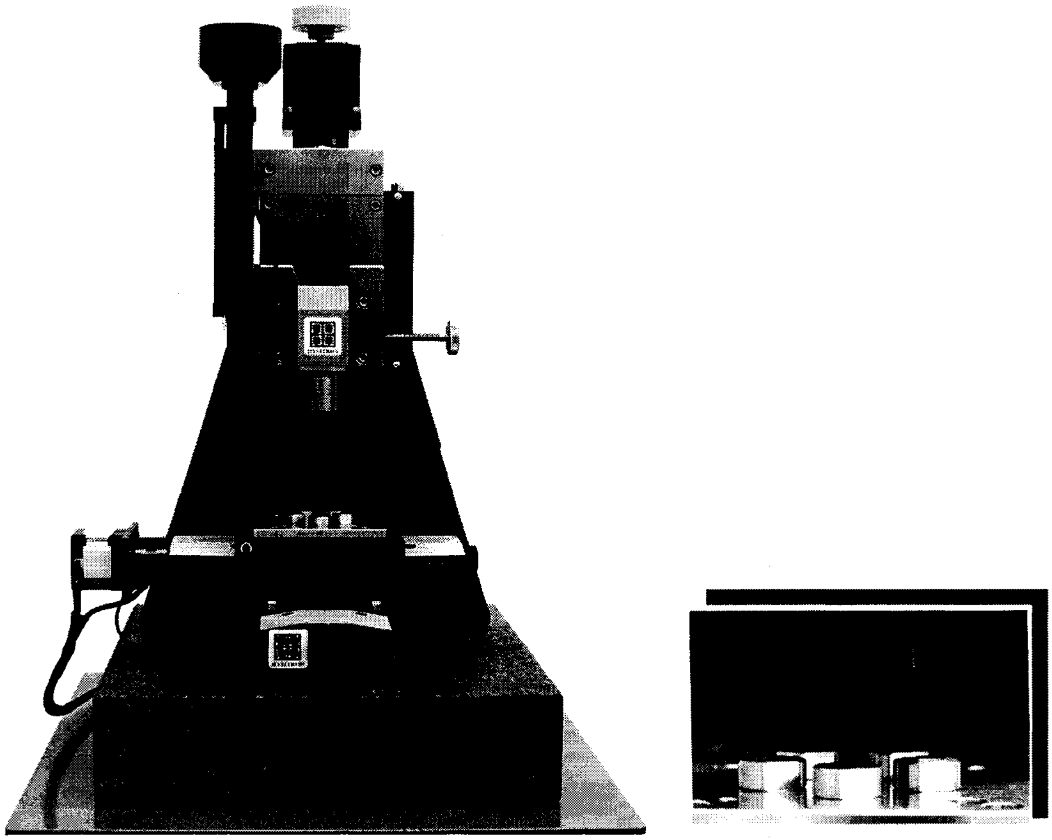


Figure 7.4: The TriboIndenter (Hysitron Inc.).

Each test sample was tested with six different applied loads ranging from 1000 to 6000 micronewtons (μN) at each of 10 different locations on its surface. This resulted in a total of 60 indentations per sample and a total of 240 indentations overall. Multiple indentations were made to more fully assess sample variability, given that these materials are considerably more heterogeneous than those traditionally tested with the Triboindenter.

The four samples, one of each raw material type, were cut from larger nodules using a diamond-tipped saw and were ground down to 11 x 11 x 6 mm in size using diamond tipped grinding wheels ranging in grit from 80 (which reduces maximum range of surface irregularity to160 microns) down to 320 (35 microns). These steps were carried out while keeping the bottom and top surfaces of each sample as close to parallel as possible. Each sample was then lapped, i.e. further ground, using a silicon carbide powder mixed with water that ranged in grit from 800 (10 microns) to 1000 (5 microns). This was done to ensure removal of all grind marks and unevenness on the samples.

For the final round of polishing each sample was mounted onto a glass slide using a cyanoacrylate mounting medium to secure the sample in place. The slides were then placed in Logitech PM2A polishing machines that use alumina oxide combined with water and ethanol glycol as a polishing agent. The polishing was done in a series of stages that include agent grits of 5 microns for 15 minutes, 3 microns for 30 minutes, 1 micron for 60 minutes and 0.5 microns for 20 minutes. The last stage was followed by one additional round of polishing with 0.3-micron grit diamond paste that lasted for 20 minutes. All polishing was done on a substrate of pellon (a polishing cloth material) and resulted in mirror finish on the top surface of each sample. The samples were then soaked in acetone for 24 hours to dissolve the cyanoacrylate holding them to the glass slides. This was followed by a 20-minute ultrasound bath in distilled water to remove any remaining residues (George Panagiotidis, 2005 pers. comm.). Once the samples were prepared they were affixed to the Triboindenter stage for indentation (*Figure 7.5*).

Along with the hardness data, the Triboindenter also provided topographical scans and information regarding the level of high surface smoothness on the prepared samples. While this provides only a preliminary assessment of microtopographic variability, it does highlight that differences do exist and therefore certainly play a role in determining rates of wear accrual. Using the above described indentation technique can provide data essential for precise and consistent interpretation of archaeological wear traces.

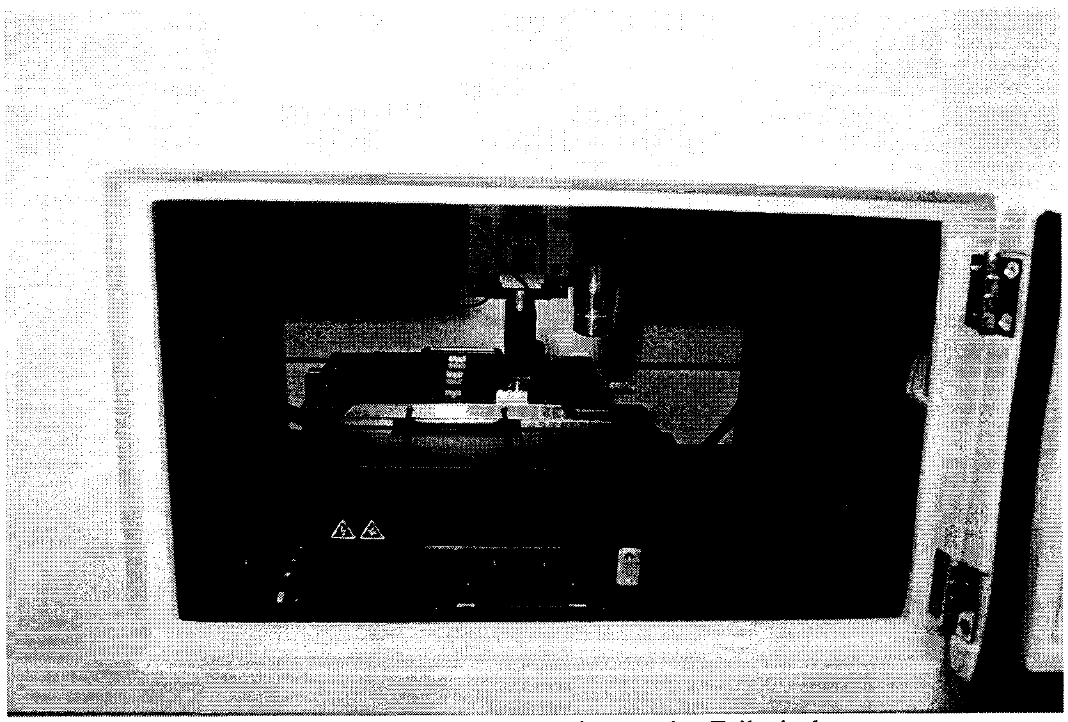


Figure 7.5: The four 1 x 1 x 0.5 cm samples on the Triboindenter stage, one directly under the indenter tip and the other three lined up on the left.

Results

Figure 7.6 is an example of a typical output screen generated by the Hysitron software. The collective output of the hardness tests recorded notable differences in the relative hardness of each raw material. From hardest to softest the four raw materials ranked as follows: San Juan Fossiliferous chert (SJF) with a mean hardness of 12.08 Giga-Pascals (GPa), Yellow Silicified Wood (YSW) with 11.02 GPa, Morrison Undifferentiated Gray chert (MUG) with 9.08 GPa, and Brushy Basin chert (BB) with 8.83 GPa (*Figure 7.7*, *Table 7.1*).

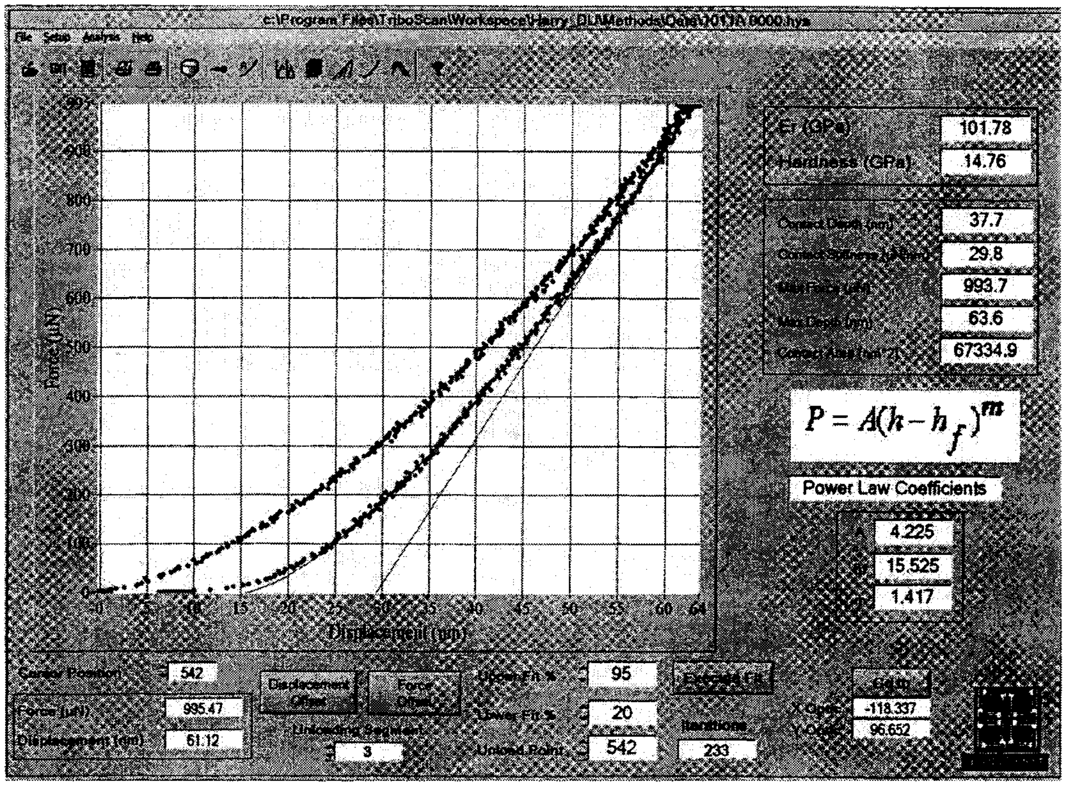


Figure 7.6: Output from Hysitron software for a single indentation on SJF chert.

Thus a lower GPa value indicates a relatively soft material and a higher value a relatively hard material. These results were corroborated by data generated concerning the overall size of the area on the sample surface that came into contact with the indenter tip and maximum depth of penetration. Both of these measures reflect the same hardness ranking described above. Harder materials, SJF and YSW, are characterized by indentations with smaller contact areas and shallower

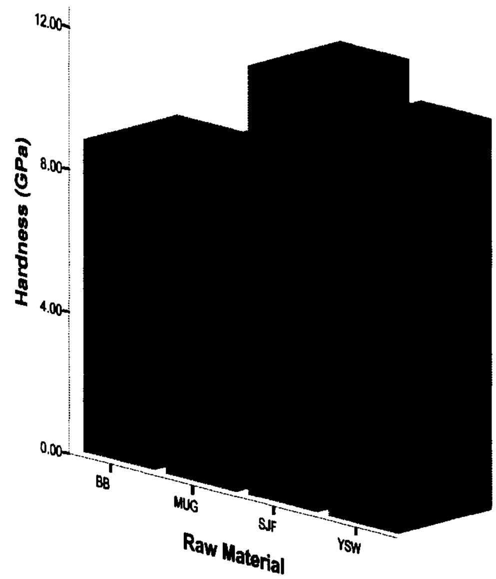


Figure 7.7: Bar graph of hardness by raw material.

depths, whereas softer materials exhibit indentations with larger contact areas and greater depths (see *Figures 7.8* and *7.9* respectively). Figure 7.10 shows this relationship via images of single indentations on each raw material captured with the Hysitron Triboindenter's integrated atomic force microscope. These indentations were all made with the same applied load of 6000 μN, thus effectively conveying the influence of material hardness on the extent of surface deformation under equivalent conditions.

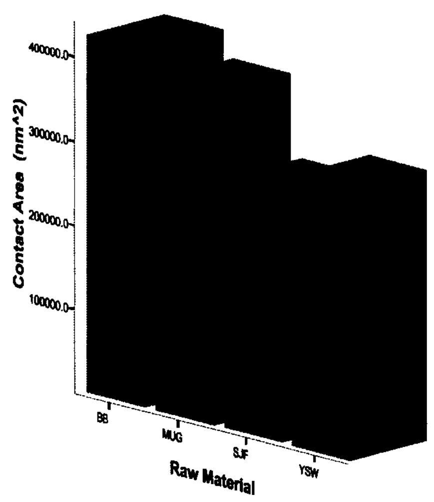


Figure 7.8: Bar graph of contact area by depth by raw material.

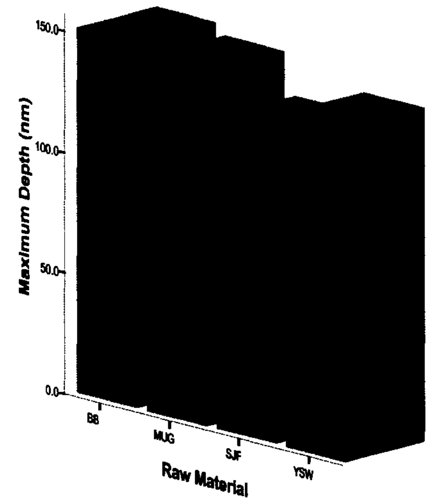


Figure 7.9: Bar graph of maximum Raw material.

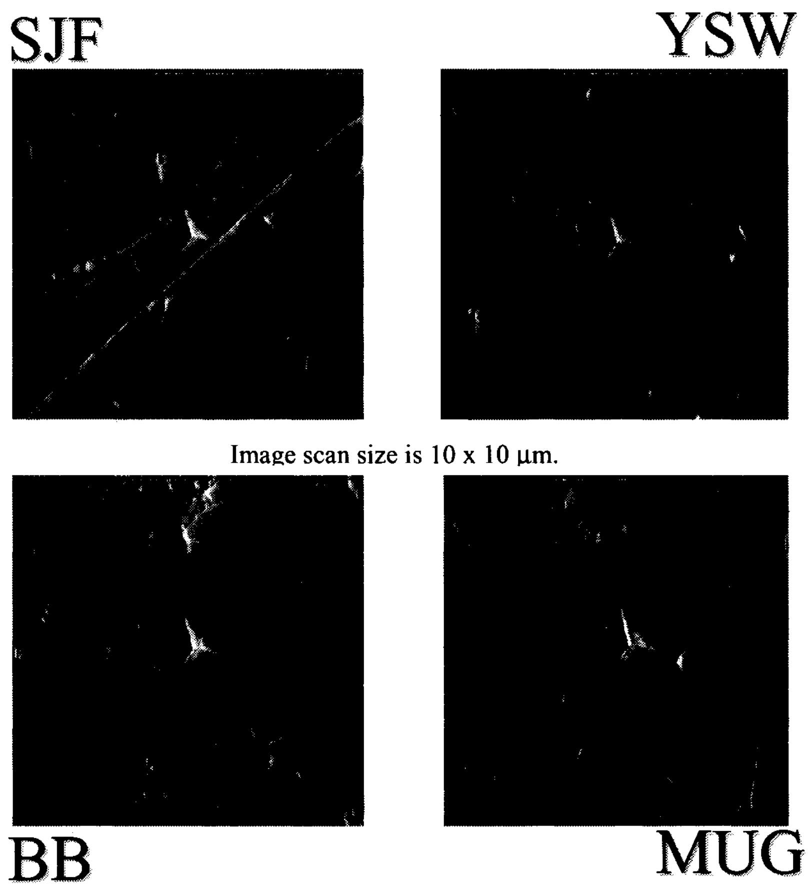


Figure 7.10: Indentations on each raw material under maximum load.

Such differences in material hardness, not surprisingly, have significant implications for interpreting archaeological wear traces. Most importantly the relative hardness of a given material will contribute to determining the rate at which wear will accrue during the course of tool use. How this influence is exerted is a complex process and is beyond the scope of this study. However, data regarding the mean variance of hardness values for each raw material have been generated and compared as a preliminary evaluation of this complexity. The variance data offers a way to gauge both material heterogeneity and the nature of the role of relative hardness in use-related wear accrual.

To be as thorough as possible, variance was assessed first in terms of applied load and then according to indent location, and as Figures 7.11 through 7.14 illustrate the results in each instance were quite similar. In terms of absolute hardness values, as measured in GPa, SJF exhibited the most variance, followed by BB, MUG and YSW, which showed the least amount of variance (Figures 11 and 12). When looking at mean variance as a percentage of the overall range of hardness values, BB actually has a higher variance than SJF, with MUG and YSW rounding things out in decreasing order (Figures 13 and 14). The mean variance in hardness values for these four raw materials shows clear differences that strongly suggest variance is a reliable indicator of material heterogeneity.

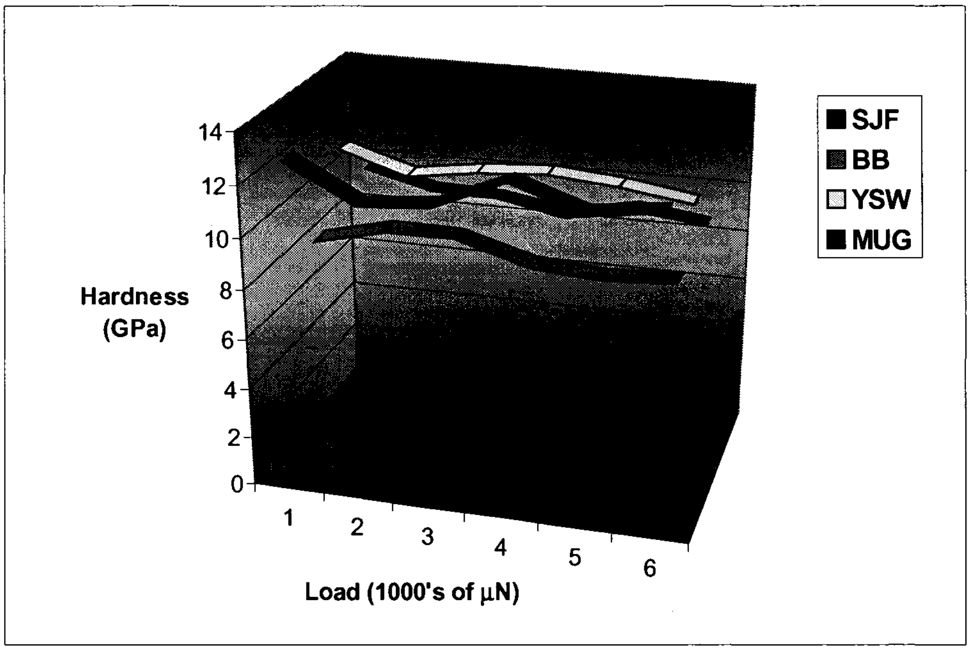


Figure 7.11: Line graph of variance in hardness by load.

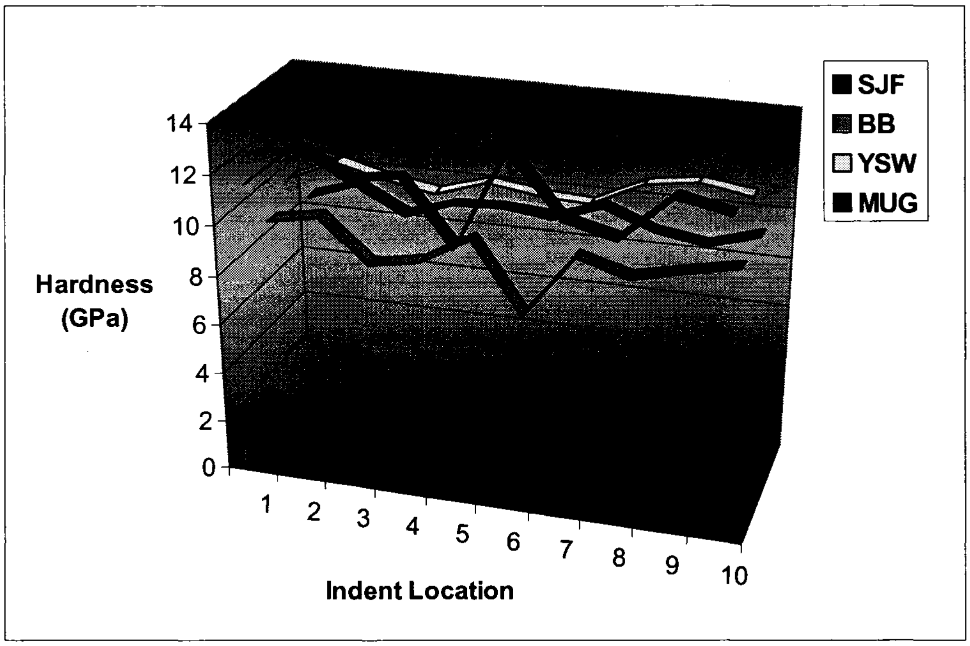


Figure 7.12: Line graph of variance in hardness by indent location.

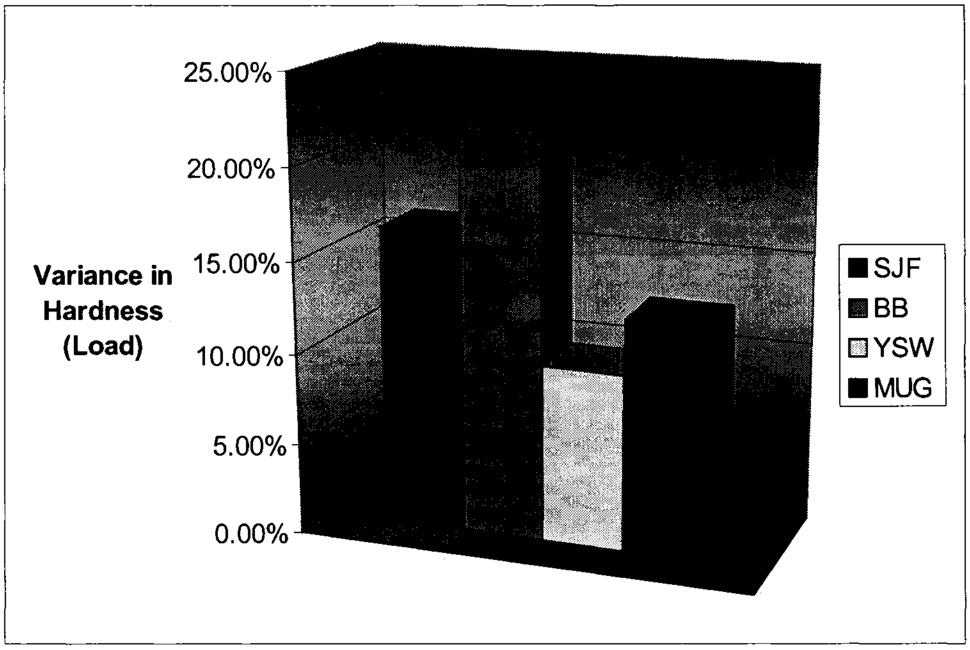


Figure 7.13: Bar graph of mean variance in hardness by load.

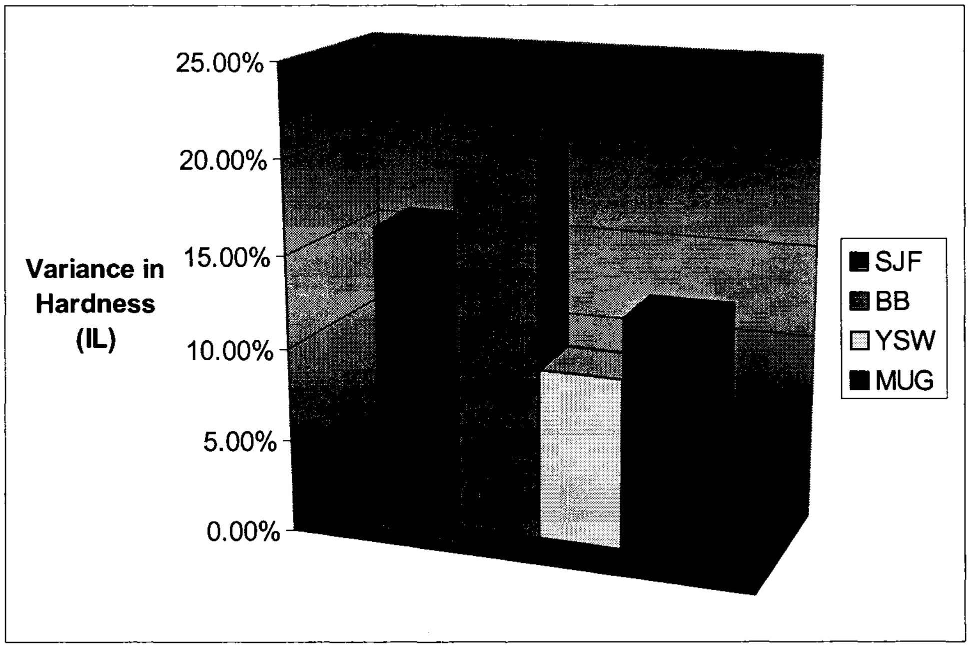


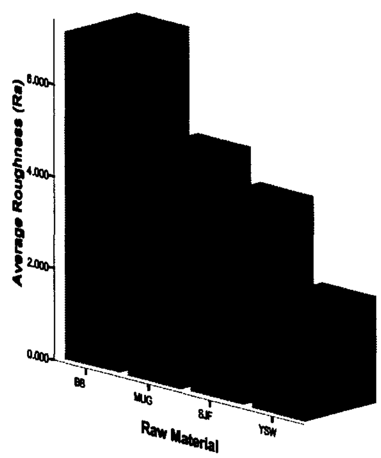
Figure 7.14: Bar graph of mean variance in hardness by indent location.

Discussion

Although most crystalline silica is characterized by a hardness value of seven on the qualitative Moh's scale, the results described above demonstrate that from one variety to another significant differences do exist and can be detected. This has important implications for lithic use-wear analysis and demands careful scrutiny when it comes to making inferences on the basis of wear form and extent. A more thorough understanding of differences in material hardness and how they affect wear development is essential to forming more reliable interpretations of function. This is particularly critical when dealing with a lithic archaeological record comprised of several different raw materials, like that of the Late Archaic FA2-13 site. The differences between the four materials under consideration are likely significant enough to have influenced the development of prehistoric wear traces. Despite its relative hardness, the greater homogeneity of YSW, for example, promoted use-wear accrual to a greater extent than was observed on the other three materials. This limits the utility of extent of wear as a basis for determining tool function, much less for assessing use intensity.

The results presented here highlight the inherent complexity of the interaction between tool and worked material surfaces during use and emphasize the need to avoid broad generalizations regarding how certain wear attributes are diagnostic of certain activities. They also suggest that in addition to differences between material types, we need to consider the possible effects of inherent variability within a single material type. The indentation of each material sample under different loads and at ten different surface locations provided data representative of both the samples overall character and of their internal variability. While quantifiable differences between the four stones were found, the results also highlighted the fact that none of these materials is perfectly homogeneous. This implies that a given tool will not accrue wear evenly across its entire surface, representing a factor which must also be considered when interpreting wear traces in behavioural, and ultimately cultural, terms.

Hardness, however, is only part of the equation for the relationship between material properties and wear accrual rates. Micro-topographic variability or surface roughness also plays an important part in how wear develops. The Triboindenter tests also yielded data regarding sample surface roughness that offer some preliminary insight into how the respective surface characteristics of each raw material may influence wear accrual over time. These data indicate that YSW exhibits the least amount of microtopographic variability; BB, on the other hand, is the most variable material micro-topographically, and SJF and MUG are intermediate in order of decreasing variability (*Figures 7.15* and *7.16*, *Table 7.2*). Figure 7.17 illustrates these differences between all four raw materials in the form of three-dimensional plots of surface roughness.



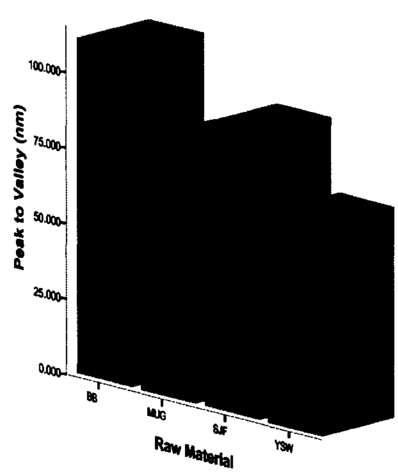


Figure 7.15: Bar graph of average roughness by raw material.

Figure 7.16: Bar graph of peak to valley distance by raw material.

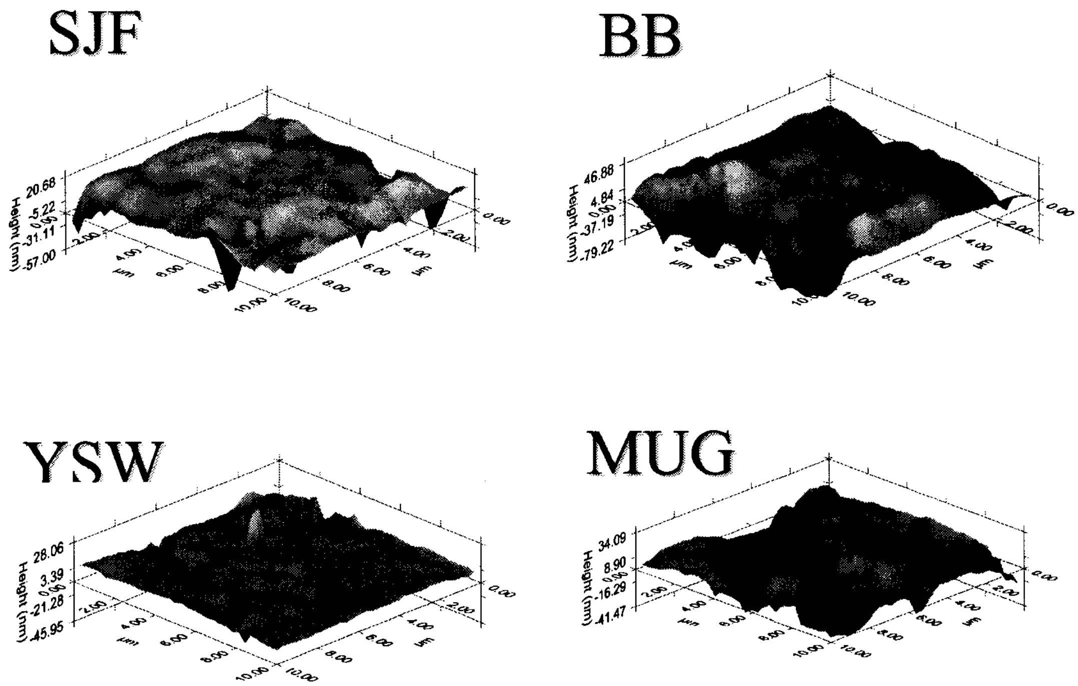
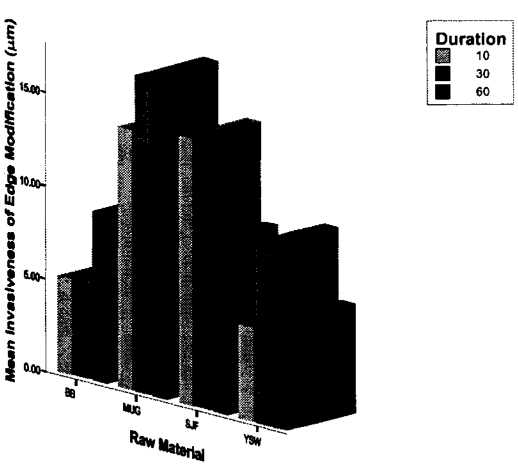


Figure 7.17: Three-dimensional plots of sample surface roughness for all four raw materials.

The analyses presented in Chapters Five and Six determined that wear developed at different rates from one raw material to the next. The nanoindenter tests demonstrate that these differences were strongly influenced by a combination of material hardness and surface roughness, albeit in complex ways. For example, when scraping a dry ungulate hide the degree of edge rounding tended to be most prominent on MUG, the second softest of the four materials, and least pronounced on YSW, the second hardest material (*Figure 7.18*). In terms of overall wear invasiveness YSW consistently developed wear more readily than any of the others and BB, the softest of the four materials, tended to accrue wear more slowly (*Figure 7.19*).

This brief example illustrates that the relationship between these two properties is indeed quite complex. The hardness data generated in the present study demonstrate that wear will typically develop more quickly the softer a material is, but that this tendency is often mitigated by material heterogeneity in the form of surface roughness. At any given point in time during use, a tool with a more even or regular surface will maintain contact with the object being modified with a larger portion of its overall surface area than will a tool with more irregular surface characteristics. In the case of the relatively hard YSW, its greater surface homogeneity promoted the development of wear, as opposed to BB with its relative softness being tempered by its more irregular surface characteristics.

The last forty years have seen considerable progress in understanding wear dynamics from both archaeological and material science perspectives. Part of these developments has involved increasing methodological overlap between these two fields of research, but as the present study can attest, a great deal more work still awaits if either



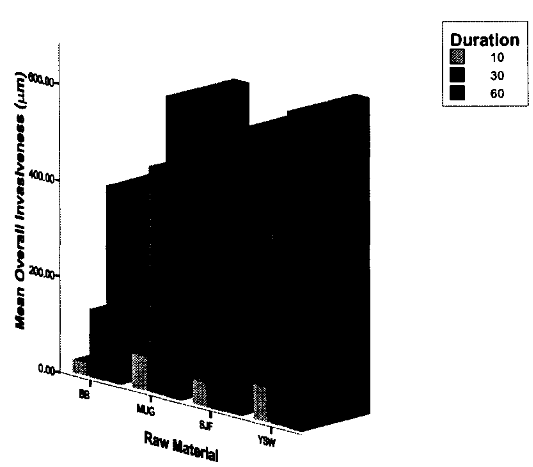


Figure 7.18: Edge modification by raw material (1st set dry hide).

Figure 7.19: Overall wear invasiveness by raw material (1st set dry hide).

discipline is to realize the full potential of this relationship. Materials science can benefit from greater insight into the complex dynamics of wear generation on heterogeneous materials, and archaeology can continue to develop more reliable methods of assessing wear traces once the influence of raw material properties is more fully understood.

Material	Location	No.	Loading (µN)	Hardness (Gpa)	Depth (nm)	Area (nm^2)
SJF	1	1	1000	14.76	63.6	67334.9
SJF	1	2	2000	10.1	102.7	197300
SJF	1	3	3000	7.43	146.6	401800
SJF	1	4	4000	10.83	150.2	368700
SJF	1	5	5000	13.16	162.6	379000
SJF	1	6	6000	12.76	178.7	470100
SJF	2	1	1000	11.95	63.5	83205.7
SJF	2	2	2000	13.16	96.4	151200
SJF	2	3	3000	13.72	119.3	217900
SJF	2	4	4000	13.89	141.5	287300
SJF	2	5	5000	13.36	168	373100
SJF	2	6	6000	13.21	181	454000
SJF	3	1	1000	8.59	72	115500
SJF	3	2	2000	12.87	94.2	154700
SJF	3	3	3000	12.88	120.9	232100
SJF	3	4	4000	11.75	144.9	339600
SJF	3	5	5000	13.63	159.2	365900
SJF	3	6	6000	12.82	179.8	468000
SJF	4	1	1000	12.95	65.9	76692.7
SJF	4	2	2000	14.43	93.6	137900
SJF	4	3	3000	11.07	124.5	269800
SJF	4	4	4000	13.87	139.7	287700
SJF	4	5	5000	11.77	164.4	423500
SJF	4	6	6000	10.4	190.8	576400
SJF	5	1	1000	10.5	71.5	94565
SJF	5	2	2000	7.79	113.1	255300
SJF	5	3	3000	11.39	127	262200
SJF	5	4	4000	10.4	151.1	383700
SJF	5	5	5000	7.3	193.3	682400
SJF	5	6	6000	12.38	183.6	484400
SJF	6	1	1000	14.93	62	66589.9
SJF	6	2	2000	11.31	98.8	176000
SJF	6	3	3000	14.21	117	210400
SJF	6	4	4000	14.71	135.1	271400
SJF	6	5	5000	12.73	161.2	391400
SJF	6	6	6000	15.58	169	385100
SJF	7	1	1000	12.73	64.5	78100.9
SJF	7	2	2000	10.69	99.5	186300
SJF	7	3	3000	10.89	125.1	274200
SJF	7	4	4000	11.35	143.6	351600
SJF	7	5	5000	11.03	165.7	452000
SJF	7	6	6000	12.37	175	484800
SJF	8	1	1000	11.37	67.6	87380.9
SJF	8	2	2000	8.34	109.5	238300
SJF	8	3	3000	12.79	119	233600
SJF	8	4	4000	12.23	142.8	326500
SJF	8	5	5000	11.32	164.3	440200

Material	Location	No.	Loading (μN)	Hardness (Gpa)	Depth (nm)	Area (nm^2)
SJF	8	6	6000	9.87	189.3	607400
SJF	9	1	1000	17.71	57.2	56189.5
SJF	9	2	2000	11.43	99.1	174200
SJF	9	3	3000	10.89	126.1	274300
SJF	9	4	4000	13.25	135.7	301200
SJF	9	5	5000	10.82	164.9	460900
SJF	9	6	6000	12.57	175.2	477000
SJF	10	1	1000	12.35	64.4	80421.8
SJF	10	2	2000	13.14	91	151600
SJF	10	3	3000	10.54	125	283200
SJF	10	4	4000	15.19	135.2	262700
SJF	10	5	5000	13.23	156.3	377000
SJF	10	6	6000	9.96	189.7	602000
BB	1	1	1000	11.15	68.6	89047.5
BB	1	2	2000	10.15	107	196000
BB	1	3	3000	10.26	133.6	291100
BB	1	4	4000	6.45	187	618300
BB	1	5	5000	9.27	182.8	537500
BB	1	6	6000	8.76	208.9	684500
BB	2	1	1000	10.17	74.7	97491.3
BB	2	2	2000	9.16	110.6	217100
BB	2	3	3000	9.17	140.5	325700
BB	2	4	4000	8.1	165.9	492800
BB	2	5	5000	9.63	181.7	517400
BB	2	6	6000	12.01	187.1	499400
BB	3	1	1000	6.96	79.4	142400
BB	3	2	2000	9.55	106.5	208200
BB	3	3	3000	9.09	143.8	328100
BB	3	4	4000	9.29	165.8	429200
BB	3	5	5000	4.37	241	1140000
BB	3	6	6000	8.56	214.8	700700
BB	4	1	1000	9.15	77.4	108300
BB	4	2	2000	9.91	107.5	200600
BB	4	3	3000	7.77	147.2	384300
BB	4	4	4000	10.37	155.2	384600
BB	4	5	5000	7.78	204.1	640500
BB	4	6	6000	5.18	244.9	1156000
BB	5	1	1000	9.1	77.8	108900
BB	5	2	2000	8.31	111.4	239200
BB	5	3	3000	10.07	133.5	296500
BB	5	4	4000	11.82	146.7	337600
BB	5	5	5000	8.72	192.6	571100
BB	5	6	6000	9.04	208.3	663200
BB	6	1	1000	3.79	109.1	260200
BB	6	2	2000	10.2	110.9	194900
BB	6	3	3000	3.98	185.5	748600
BB	6	4	4000	4.09	215.7	974000

Material	Location	No.	Loading (μN)	Hardness (Gpa)	Depth (nm)	Area (nm^2)
BB	6	5	5000	8.3	187.8	600200
BB	6	6	6000	9.63	200.7	622600
BB	7	1	1000	7.55	81.9	131200
BB	7	2	2000	7.48	121.6	265700
BB	7	3	3000	15.09	114.7	198100
BB	7	4	4000	9.34	172.3	427100
BB	7	5	5000	7.36	205.9	676900
BB	7	6	6000	8.89	210.4	674100
BB	8	1	1000	7.6	79.6	130300
BB	8	2	2000	8.41	115	236300
BB	8	3	3000	9.82	133.5	304100
BB	8	4	4000	9.19	162.3	434200
BB	8	5	5000	10.06	178.9	495500
BB	8	6	6000	7.13	225.7	840900
BB	9	1	1000	10.46	72.4	94877.9
BB	9	2	2000	10.05	104.4	197800
BB	9	3	3000	7.97	146.7	374500
BB	9	4	4000	9.32	163.1	428300
BB	9	5	5000	8.63	185.3	577700
BB	9	6	6000	8.56	216.3	700400
BB	10	1	1000	11.17	62.8	89011.6
BB	10	2	2000	10.62	104.6	187200
BB	10	3	3000	10.81	129.9	276400
BB	10	4	4000	7.86	172.9	507700
BB	10	5	5000	9.46	185.2	526700
BB	10	6	6000	7.82	219.1	766500
YSW	1	1	1000	10.41	73.5	95295.5
YSW	1	2	2000	9.94	110.5	200300
YSW	1	3	3000	11.47	132.9	260300
YSW	1	4	4000	9.96	164.6	400300
YSW	1	5	5000	10.67	181	467100
YSW	1	6	6000	9.61	209.5	623700
YSW	2	1	1000	10.12	75.3	97911.2
YSW	2	2	2000	11.06	107	179800
YSW	2	3	3000	10.77	136	277300
YSW	2	4	4000	13.91	147.6	287000
YSW	2	5	5000	10.27	183.7	485400
YSW	2	6	6000	11.07	197.2	542000
YSW	3	1	1000	14.11	66.3	70417.5
YSW	3	2	2000	10.81	108.1	183900
YSW	3	3	3000	10.64	137	280700
YSW	3	4	4000	10.27	159.9	388600
YSW	3	5	5000	9.48	188.8	525600
YSW	3	6	6000	8.87	209.5	676000
YSW	4	1	1000	10.05	72.9	98728.6
YSW	4	2	2000	11.29	104.3	176300
YSW	4	3	3000	9.92	137	301000

Material	Location	No.	Loading (µN)	Hardness (Gpa)	Depth (nm)	Area (nm^2)
YSW	4	4	4000	10.19	159.2	391500
YSW	4	5	5000	9.84	183.2	506800
YSW	4	6	6000	10.99	196.4	545700
YSW	5	1	1000	11.59	69.3	85620.4
YSW	5	2	2000	11.34	102.7	175400
YSW	5	3	3000	11.18	129.5	267100
YSW	5	4	4000	10.82	157.1	368800
YSW	5	5	5000	11.06	174.2	450700
YSW	5	6	6000	10.14	200.7	591600
YSW	6	1	1000	11.77	70.4	84345.7
YSW	6	2	2000	9.78	109.8	203300
YSW	6	3	3000	9.99	136.7	298800
YSW	6	4	4000	11.07	153.2	360600
YSW	6	5	5000	10.96	173.6	454800
YSW	6	6	6000	10.87	194.3	551800
YSW	7	1	1000	10.92	69.7	90856
YSW	7	2	2000	11.13	102.4	178700
YSW	7	3	3000	10.34	133.4	289000
YSW	7	4	4000	10.53	153.3	378800
YSW	7	5	5000	10.35	176.1	481400
YSW	7	6	6000	10.6	195.2	565700
YSW	8	1	1000	12.05	67.5	82403.3
YSW	8	2	2000	9.77	105.8	203600
YSW	8	3	3000	11.62	127.3	257100
YSW	8	4	4000	12.35	145	323200
YSW	8	5	5000	12.35	168.1	403600
YSW	8	6	6000	11.52	194.1	520700
YSW	9	1	1000	11.03	70.6	90064.9
YSW	9	2	2000	11.42	101.1	174300
YSW	9	3	3000	12.5	121.8	239100
YSW	9	4	4000	12.76	140.5	312900
YSW	9	5	5000	13.43	157.4	371400
YSW	9	6	6000	10.3	187.9	582200
YSW	10	1	1000	12.93	63.9	76888.9
YSW	10	2	2000	10.13	105	196400
YSW	10	3	3000	12.09	122.9	247200
YSW	10	4	4000	10.71	150.4	372600
YSW	10	5	5000	11.67	166.1	427400
YSW	10	6	6000	12.15	183.7	493800
MUG	1	1	1000	10.36	73.7	95721.3
MUG	1	2	2000	8.87	110.7	224500
MUG	1	3	3000	8.93	137.9	334700
MUG	1	4	4000	8.23	172	484900
MUG	1	5	5000	8.68	187.6	574100
MUG	1	6	6000	7.93	215.4	755700
MUG	2	1	1000	12.18	67.2	81525.2
MUG	2	2	2000	8.15	116.9	243900

Material	Location	No.	Loading (µN)	Hardness (Gpa)	Depth (nm)	Area (nm^2)
MUG	2	3	3000	7.89	144.9	378300
MUG	2	4	4000	9.55	158.2	418100
MUG	2	5	5000	9.86	178.2	505500
MUG	2	6	6000	9.3	200	645100
MUG	3	1	1000	7.24	78.6	136900
MUG	3	2	2000	9.73	106.9	204400
MUG	3	3	3000	8.12	142.5	367400
MUG	3	4	4000	9.04	163.2	441200
MUG	3	5	5000	7.97	193.8	625100
MUG	3	6	6000	8.69	206.2	690300
MUG	4	1	1000	9.88	71.8	100400
MUG	4	2	2000	9.71	108.3	204900
MUG	4	3	3000	7.82	147.5	381900
MUG	4	4	4000	8.32	173.1	479400
MUG	4	5	5000	9.75	182.9	511500
MUG	4	6	6000	9.46	200	634100
MUG	5	1	1000	8.69	78.5	114100
MUG	5	2	2000	10	105.9	198900
MUG	5	3	3000	9.85	138	303200
MUG	5	4	4000	8.89	162.5	448600
MUG	5	5	5000	9.69	180	514600
MUG	5	6	6000	8.29	210.5	723500
MUG	6	1	1000	10.01	72	99083.5
MUG	6	2	2000	10.06	106.8	197800
MUG	6	3	3000	9.75	132	306300
MUG	6	4	4000	8.41	170.8	474200
MUG	6	5	5000	8.84	183.7	563600
MUG	6	6	6000	7.29	221.5	822000
MUG	7	1	1000	10.53	71	94221.6
MUG	7	2	2000	10.25	104.9	194100
MUG	7	3	3000	9.38	145.4	318300
MUG	7	4	4000	8.89	168.6	448800
MUG	7	5	5000	10.42	179.4	478200
MUG	7	6	6000	8.85	212.8	677500
MUG	8	1	1000	13	67.4	76379.7
MUG	8	2	2000	6.56	125.8	303000
MUG	8	3	3000	8.89	139.1	335700
MUG	8	4	4000	6.88	180.2	579900
MUG	8	5	5000	8.22	193.2	606500
MUG	8	6	6000	10.22	194.1	587100
MUG	9	1	1000	6.61	83.1	150000
MUG	9	2	2000	9.09	111.1	218600
MUG	9	3	3000	9.74	135.6	306700
MUG	9	4	4000	8.08	173	493300
MUG	9	5	5000	9.35	182.8	533300
MUG	9	6	6000	8.81	205.5	680900
MUG	10	1	1000	10.01	72	99132.2

Material	Location	No.	Loading (µN)	Hardness (Gpa)	Depth (nm)	Area (nm^2)
MUG	10	2	2000	9.12	111.3	218100
MUG	10	3	3000	10.08	132.3	296200
MUG	10	4	4000	9.19	161.7	434300
MUG	10	5	5000	8.45	187.7	589700
MUG	10	6	6000	8.62	204.8	695300

Table 7.1: Nanoindenter material hardness test data by sample location and indentation number.

Material	Location	Number	Average Roughness (Ra)	Peak to Valley (nm)
SJF	1	1	2.303	96.982
SJF	2	1	2.141	51.595
SJF	3	1	2.955	101.576
SJF	4	1	5.16	143.796
SJF	5	1	3.758	77.983
SJF	6	1	2.576	91.704
SJF	7	1	5.438	115.794
SJF	8	1	2.424	59.418
SJF	9	1	3.372	130.137
SJF	10	1	3.693	86.613
SJF	1	2	3.378	102.57
SJF	2	2	1.957	46.318
SJF	3	2	2.495	78.604
SJF	4	2	4.634	90.835
SJF	5	2	6.472	113.249
SJF	6	2	5.337	116.415
SJF	7	2	5.578	99.589
SJF	8	2	2.31	32.534
SJF	9	2	3.69	53.52
SJF	10	2	2.737	50.85
SJF	1	3	9.34	170.556
SJF	2	3	3.041	57.804
SJF	3	3	9.399	187.879
SJF	4	3	1.471	30.672
SJF	5	3	2.968	68.483
SJF	6	3	1.3	66.807
SJF	7	3	6.369	115.236
SJF	8	3	5.207	124.673
SJF	9	3	3.436	85.62
SJF	10	3	3.133	55.507
SJF	1	6	4.736	93.07
SJF	2	6	7.42	179.497
SJF	3	6	4.134	133.365
SJF	4	6	3.926	107.909
SJF	5	6	5.214	86.427

Material	Location	Number	Average Roughness (Ra)	Peak to Valley (nm)
SJF	6	6	2.038	70.78
SJF	7	6	3.658	94.374
SJF	8	6	8.548	123.307
SJF	9	6	3.195	68.483
SJF	10	6	5.474	115.484
BB	1	1	5.925	104.618
BB	2	1	6.682	108.592
BB	3	1	4.442	80.28
BB	4	1	12.637	214.39
BB	5	1	6.485	90.773
BB	6	1	29.109	436.79
BB	7	1	4.953	77.734
BB	8	1	4.422	49.298
BB	9	1	3.391	38.308
BB	10	1	7.474	88.786
BB	1	2	9.036	176.765
BB	2	2	5.541	118.775
BB	3	2	4.859	119.83
BB	4	2	6.309	90.897
BB	5	2	5.352	69.042
BB	6	2	8.732	106.543
BB	7	2	7.69	108.903
BB	8	2	4.728	51.782
BB	9	2	4.923	70.346
BB	10	2	4.926	70.098
BB	1	3	8.225	113.683
BB	2	3	8.871	119.892
BB	3	3	5.694	104.867
BB	4	3	4.476	82.267
BB	5	3	5.19	58.984
BB	6	3	8.391	143.92
BB	7	3	11.643	189.741
BB	8	3	5.872	112.131
BB	9	3	4.47	90.338
BB	10	3	3.608	61.84
BB	1	6	8.42	132.31
BB	2	6	4.375	112.193
BB	3	6	4.324	59.17
BB	4	6	13.38	204.642
BB	5	6	13.555	153.792
BB	6	6	4.357	55.258
BB	7	6	4.366	106.543
BB	8	6	10.232	155.344
BB	9	6	4.142	43.213
BB	10	6	5.094	91.145
YSW	1	1	2.393	72.146
YSW	2	1	3.87	77.362

Material	Location	Number	Average Roughness (Ra)	Peak to Valley (nm)
YSW	3	1	1.316	49.174
YSW	4	1	1.685	76.803
YSW	5	1	1.892	52.589
YSW	6	1	1.72	78.852
YSW	7	1	1.299	45.759
YSW	8	1	1.517	56.873
YSW	9	1	7.482	143.486
YSW	10	1	1.324	28.436
YSW	1	2	1.34	44.517
YSW	2	2	3.161	80.156
YSW	3	2	1.581	52.899
YSW	4	2	1.299	53.83
YSW	5	2	1.398	47.311
YSW	6	2	1.814	74.568
YSW	7	2	1.422	40.357
YSW	8	2	1.613	35.577
YSW	9	2	2.419	75.872
YSW	10	2	3.435	140.816
YSW	1	3	1.39	41.599
YSW	2	3	10.436	240.902
YSW	3	3	1.72	57.494
YSW	4	3	1.652	53.396
YSW	5	3	1.278	51.036
YSW	6	3	1.848	66
YSW	7	3	1.939	37.315
YSW	8	3	2.453	54.886
YSW	9	3	1.914	67.117
YSW	10	3	3.244	70.905
YSW	1	6	1.292	50.974
YSW	2	6	2.726	83.819
YSW	3	6	2.579	87.544
YSW	4	6	1.882	71.836
YSW	5	6	2.128	80.032
YSW	6	6	1.41	64.882
YSW	7	6	2.002	75.127
YSW	8	6	1.979	55.755
YSW	9	6	2.562	72.457
YSW	10	6	3.01	96.423
MUG	1	1	6.579	100.831
MUG	2	1	6.952	152.675
MUG	3	1	4.056	229.602
MUG	4	1	7.666	151.868
MUG	5	1	6.343	113.87
MUG	6	1	2.851	57.432
MUG	7	1	4.955	80.59
MUG	8	1	5.983	90.711
MUG	9	1	4.599	67.366

Material	Location	Number	Average Roughness (Ra)	Peak to Valley (nm)
MUG	10	1	3.882	93.07
MUG	1	2	4.737	61.343
MUG	2	2	6.319	107.785
MUG	3	2	5.863	86.427
MUG	4	2	3.223	77.796
MUG	5	2	4.445	35.514
MUG	6	2	5.017	73.078
MUG	7	2	5.063	81.832
MUG	8	2	8.014	108.778
MUG	9	2	4.913	55.258
MUG	10	2	3.031	52.527
MUG	1	3	2.932	59.667
MUG	2	3	4.761	89.966
MUG	3	3	4.049	66.31
MUG	4	3	4.258	51.533
MUG	5	3	6.293	53.396
MUG	6	3	4.122	55.445
MUG	7	3	4.142	86.365
MUG	8	3	2.665	56.252
MUG	9	3	2.95	80.777
MUG	10	3	5.538	131.503
MUG	1	6	4.539	53.955
MUG	2	6	6.489	88.972
MUG	3	6	4.28	40.357
MUG	4	6	7.465	79.907
MUG	5	6	5.578	84.254
MUG	6	6	3.105	53.334
MUG	7	6	4.218	62.833
MUG	8	6	1.76	62.026
MUG	9	6	7.451	118.278
MUG	10	6	4.767	93.691

Table 7.2: Nanoindenter sample surface roughness data for four of the six test locations on each sample.

CHAPTER 8: SUMMARY AND CONCLUSIONS

Summary

Since the late nineteenth century archaeologists have been fascinated by the prehistoric cultures of the Southwestern United States. Architecture and ceramics have been the most frequent subjects of archaeological inquiry, given their prominence and ubiquity on the Southwestern landscape. As a result, they are the best-understood components of this region's material culture. Since they are most commonly associated with the Basketmaker and Pueblo peoples, the later prehistory of the southwest has been documented in much greater detail than the earlier Paleo-Indian or Archaic periods.

There are, however, several studies that have focused on the earliest human populations in the southwest. They have often involved examinations of subsistence strategies as reflected in mobility patterns and associated technologies. A great deal regarding these strategies has been inferred through the analyses of chipped stone tools. The most prolific form of analysis focusing on early lithic technology in the Four-Corners area has, and continues to be, typological in nature. Despite this fairly strict adherence to typological interpretations, the study of Paleo-Indian and Archaic technologies has increased in scope and sophistication in recent years (e.g. Adovasio, Donahue, and Stukenrath, 1990; Beckett and MacNeish, 1994; Bradley, 1993; Haynes, 1993; Hicks, 1994; Parry, Smiley, and Burgett, 1994; Schutt, 1980). This process of methodological growth can also be seen among studies of Puebloan stone tools, but it has occurred at a much slower pace.

Alfred V. Kidder (1932) produced one if the earliest systematic typologies for late prehistoric chipped stone tools in the American Southwest. His research at Pecos Pueblo provided what has become a standard framework for classifying lithic artifacts from the prehistoric Pueblo period. One of the many analytical precedents he helped to establish is a continual emphasis on projectile technologies as a primary means of chronological interpretation (e.g. Cameron, 2001; Davis, 1985; Jelinek, 1967; Kamp and Whittaker, 1999; Lekson, 1990; O'Hara, 1988; Phagan, 1988a, 1988b; White, Papworth, and Binford, 1963). This emphasis is a result of their relatively high volume of production and the greater amount of energy invested in their manufacture compared to short-term use implements. Kidder subdivided the Pecos projectile assemblage into various types based largely on outline shape. He saw the simple segregation of different gross morphologies as analytically sufficient for gleaning all the cultural information one could from stone tools.

This basic approach to lithic analysis dominates the research done to date on Southwestern stone technologies. Studies of Pueblo lithics in particular frequently appear as relatively brief chapters detailing assemblage contents in larger volumes primarily concerned with ceramics and/or architecture. The last twenty-five years, however, have seen a partial expansion in the range of approaches taken in the study of prehistoric stone tools. The increase in use of statistics to identify patterns in attribute morphology and their functional relevance is one area that has recently been explored in greater detail (e.g. Phagan, 1984, 1988a, 1988b). Another is the application of low power microscopic use-wear analysis to Puebloan chipped stone tools (e.g. Berg, 1993; Nelson, 1984; Neusius, 1988). A further area of expansion relates to the use of stylistic attributes in an attempt to isolate the products of individual knappers (e.g. Whittaker, 1984; 1987a; 1987b). These innovations in lithic research have begun to re-direct the attentions of analysts towards more comprehensive approaches with the potential for yielding considerably more cultural information from these implements than do traditional typological studies.

The potential of these new avenues of inquiry, however, has yet to be fully realized. Although the directions taken thus far involve changes in how chipped stone tools are perceived in both technological and functional terms, they have not gone far enough. A basic tenet of lithic analysis that has underlain this field of research since its formal inception is that all stone tools represent normative concepts or ideas and therefore the desired end products envisioned by their producers. This assumption is an oversimplification. What has rarely been taken into account is how such implements changed morphologically, and often functionally, during the course of their post-production use histories. Chipped stone tools are a far more dynamic medium than has been acknowledged in the literature. Following their production, many tools were subjected to repeated episodes of use increasing their morphological variability. This almost certainly extends beyond what is typically recognized given the interpretative limits inherent in traditional forms of analysis. Research carried out by Goodyear (1974), Kay (1977), Hoffman (1985), and Shott (1995a), to name a few, are indicative of the kind of use-life-based approach that has been taken in the present study and that should be adopted by all lithic analysts working in the American Southwest and elsewhere.

In addition to this use-life-based perspective, any given study of chipped stone tools should incorporate multiple analytical tacks to act as a system of analytical checks and balances. The standardization of use-wear analysis as part of any functional lithic analysis, in conjunction with more sophisticated quantitative measures and statistical tests, has enormous potential for shedding light on how a particular group of prehistoric peoples lived their lives. This shift from static to more dynamic views of chipped lithic technology will undoubtedly improve our ability to derive cultural information from this prolific component of material culture and in turn compliment what we have learned from the rest of the archaeological record.

From the start, this dissertation has been guided by a perceived need for a revised and expanded approach to flaked stone tool analysis in the Southwest. The second and third chapters have dealt with the origins and development of lithic analysis in this region. A common characteristic of almost all lithic research in the Four-Corners area is a focus on the initial production of stone tools as a means of functionally classifying them. It is generally accepted that a given specimen could have been recycled into an entirely different tool form following extensive damage, but little effort has been made to understand how tools change in appearance and use as a result of progressive wear accrual. This more gradual form of reduction represents a largely unexplored aspect of Southwestern lithic technology.

A number of studies outside the Southwest have explored these changes and the processes that drove them (e.g. Goodyear, 1974; Hoffman, 1985; Kay, 1977, Shott, 1995a). Albert C. Goodyear (1974) examined an assemblage of Late Paleo-Indian Dalton points from northeastern Arkansas, and C. Marshall Hoffman (1985) analyzed a collection of points from the Late Archaic to Early Woodland Brinkley site in northeastern Mississippi. What both of these researchers attempted to do, using somewhat similar approaches, was to trace the morphological evolution of these tools to test some implicit assumptions of the traditional normative typologies for these regions and time periods. These classifications generally assume that variation in outline shape is correlated directly to variation in function, implying the presence of distinct tool types. Most typologies do not include any consistent means of differentiating between purposefully introduced variation in tool form and variation generated through progressive use and maintenance. Both Goodyear and Hoffman recognize that chipped stone tools underwent continuous modification from their initial stages of production through multiple episodes of use and rejuvenation.

Beyond the realm of projectile technologies, Marvin Kay (1977) employed a combination of use-wear traces and metric attributes in an attempt to identify the most reliable variables for detecting individual variation in unifacial end scrapers from the Middle Woodland Imhoff site in central Missouri. Inherent in his approach is recognition of the fact that such implements were constantly changing in shape as a response to specific kinds of use. Michael J. Shott (1995a), as a further example, considered the assemblage of end scrapers from the Paleo-Indian Leavitt site in Michigan from the perspective of curation and use rates. Here again the focus of analysis is on post-manufacture tool reduction over time. Shott compared the values of a number of metric attributes between tools that he recognized as being representative of different stages of curation to better understand how these scrapers evolved over the course of their functional use-lives.

The general use-life approach adopted by these authors is equally applicable to lithic technology from the American Southwest. Although Southwestern chipped lithics, particularly those from the Puebloan period, are often recognized as being designed for shorter-term use, they would still have experienced a certain degree of modification as a result of being used. Given this, they can still be considered from a use-life-based perspective. The studies done by Whittaker (1984, 1987a, 1987b) and Phagan (1993) demonstrate that sizable lithic assemblages likely representative of two or more stages of post-manufacture tool reduction have been recovered from Southwestern archaeological contexts. The specific variables or ratios that should be employed to quantitatively identify these stages will undoubtedly be determined by the particular natures of Southwestern lithic technologies. The selection process should be directed towards those attributes that would have been most susceptible to modification during the course of use. The inclusion of either low or high-power microscopy, depending on the attributes chosen, will reinforce macroscopically derived functional interpretations and enable detection of finer scale variation in tool form as it relates to changes in use over time.

Ultimately, greater caution must be taken when associating a pre-defined type or category with a particular tool. All processes that contributed to the final form of a given tool, from initial production through subsequent use and discard, need to be considered prior to its being granted a specific functional, and therefore typological, status. These tools represent a far more dynamic medium that is generally conceded for this component of prehistoric material culture. Despite their lack of more obvious stylistic attributes, stone tools can still reveal a great deal about prehistoric populations and their lifeways. This can be accomplished by examining in greater detail the relationship between the form and function of a given tool throughout the course of its life history. This perspective can then be further refined to allow consideration of how other variables may influence this relationship. This dissertation has focused on evaluating the impact raw material selection had on tool form and use over time.

Stone tool life histories as a framework for analysis is still in its infancy and must be viewed as only a first step in a much longer, and much needed, process of theoretical and methodological refinement. The quantitative techniques developed by the investigators discussed above need to be expanded upon in a number of ways. Consideration of a wider range of attributes, including microscopic use-wear traces and ratios of related morphological traits, should be a standard practice. The temporal, as well as spatial, applicability of a use-life based-approach should also be expanded. In North America the more notable contributions in this area of research have been focused primarily, although not exclusively, on materials from the eastern United States, and on the Middle Archaic through Early Woodland periods. This perspective can be tailored for the study of lithic technology outside eastern North America, and applied to other prehistoric periods.

Experimentation is of course critical for refining any methodology. Experiments have always served as a testing ground for hypotheses that has allowed us to evaluate and improve our analytical techniques. The specific purpose and structure of an experiment, however, are governed by prevailing analytical concerns, which for lithics has primarily involved recognition of static types rather than assessments of dynamic processes.

Although the last thirty years have been witness to a slow increase in the number of experimental studies that recognize the considerable variability of lithic technologies (e.g. Goodyear, 1974; Flenniken, 1985; Bradbury and Carr, 1999; Carr and Bradbury, 2001; Clarkson, 2002), the majority of experiments have emphasized the consistency of particular technologies or technological attributes in order to define specific types that can serve as a basis for future identification in the archaeological record (e.g. Bordes, 1968; Cooper, 2002; Coutier, 1929; Dibble and Whittaker, 1981; Goodman, 1944; Hayden and Hutchens, 1989; Keeley, 1980; Kimball, Kimball, and Allen, 1995; Knowles, 1953; Kvamme, 1997; Morrow, 1996; Odell and Cowan, 1986; Patterson, 1998; Pei, 1936; Pelcin, 1997a/b/c; Prentiss, 1998; Speth, 1972; Stemp and Stemp, 2001; Tringham *et al.*, 1974; Vaughan, 1985; Warren, 1914). Most experimental studies acknowledge that several sources of variability existed in the past, but relatively few attempt to deal directly with more than one or two of them. While it is necessary to first understand all basic cause-and-effect relationships involved, it is also important to build on this foundation to create the type of analytical infrastructure required to effectively deal with the inherent complexities of prehistoric technologies and lifeways. The future of lithic experimentation must continue to include testing of new analytical techniques to keep pace with advancements in scientific technology, and standardize more comprehensive archaeological testing of both existing and future approaches. Future experiments need to be more inclusive methodologically, the lines between the experiment 'types' described above need to be broken down and these categories merged as a procedural response to the interpretive challenge of inherently complex prehistoric lithic technologies. What is being argued here is that not only do we need to more widely adopt châine opératoire-type approaches, but that we must also be more rigorous and systematic in their implementation. Despite the considerable contributions châine opératoire has made to our understanding of lithic technology, there is still a tendency to emphasize production over use, resulting in less than complete pictures of lithic industries. Châine opératoire research is clearly a significant step in the right direction, but we must continue to refine our methods to further our understanding of the articulation between past technologies and their producers. Experimentation in archaeology, and lithics in particular, has unquestioningly come a very long way over the last century and a half, but it is just beginning to hit its stride, offering tantalizing hints of the potential it has for considerably refining our interpretations of the archaeological record and the lifeways it represents.

Encouragement by some researchers (e.g. Flenniken, 1984) to view lithic technologies in the context of their full reduction spectra has been heeded by relatively few in North America. This is certainly a daunting task, and one fraught with complications, but one that must be taken on if we are to even begin to understand the full significance of these tools on either cultural or technological levels. The recommendation made by many lithic researchers (e.g. Keeley, 1980, Morrow, 1997) to employ multiple analytical tacks and cite multiple lines of evidence in any analysis, experimental or otherwise, needs to be extended to include the combination of techniques previously relegated to either manufacture or use-related lithic studies.

These types of studies, by their very nature, require considerable investments of time for their proper implementation. While this may appear impractical to some researchers, it represents a necessary step in furthering our understanding of the past.

All stages of such a research program need not be carried out within the context of a single study, but could perhaps be dealt with over the course of a series of related studies, each building on the results of its predecessors. Many past experimental studies represent solid starting points on promising analytical trajectories, but typically remain unexplored beyond their introduction into the literature. While experimentation has certainly undergone considerable methodological refinement over time (Ascher, 1961b; Coles, 1967, 1973, 1979; Amick, Mauldin, and Binford, 1989), our attention must now focus on how we apply experiments to the study of lithic technology to maximize the retrieval of technological, and ultimately cultural, information. We have taken the first few analytical steps, tested the interpretative waters, and now it is time to take the proverbial plunge and move away from an independent piecemeal approach to lithic studies and towards more integrated analyses of stone tool technologies.

The results presented in the last three chapters in particular highlight some important issues regarding how we currently deal with prehistoric lithic technologies and the evidence of use they often bear. Digital image analysis using the Clemex Vision software package has demonstrated that raw material properties can have a pronounced effect on how use-related wear develops over time. This finding requires that we consider these effects when making inferences about the nature of past tool use. We cannot assume that extensive wear implies longer use and that little or no wear implies limited use. Both Clemex and the Idrisi GIS analyses demonstrated that YSW experimentally accrued wear most rapidly and that equal amounts of use resulted in very different rates of use-wear accrual from one raw material to the next. They also highlighted different but related aspects of use-wear accrual. The Clemex system emphasized use-wear invasiveness, while Idrisi showcased use-wear homogeneity. Although different patterns were recognized in each case, they were shown to be complementary rather contradictory in nature.

Collectively these results illustrate that extent of wear is not always a reliable measure of use duration, but a better understanding of observed differences can offer considerable insight into many aspects of tool-using behaviour. The ability to determine how intensively a tool was used, for example, opens the door to evaluating the significance of a given activity as part of a larger subsistence strategy. The analysis of ten flake tools from the FA2-13 site revealed that the different rates of wear accrual attributed experimentally to YSW and SJF are also observable in the archaeological record. As noted by Schutt (1997a: 164), several subsistence-related tasks were carried out at FA2-13 with preliminary wear evidence suggesting an emphasis on scraping activities. The results presented here do not dispute this assertion, but offer the potential for greater insight into the nature of this emphasis than previously possible. This holds the promise of a far more detailed reconstruction of the subsistence strategy employed by the site's Late Archaic inhabitants.

It is interesting to note that initial examination of the FA2-13 chipped lithics was carried out using a Leitz Laborlux high power metallurgical incident light microscope to examine various flake tools to determine if any identifiable wear traces could be observed on such short-term use implements. The YSW artifacts consistently exhibited more homogeneous and extensive abrasive wear compared to the SJF tools, and thus were tentatively identified as having been used to work different contact materials pending comparison to experimental data. In light of the experimental results presented above, those initial examinations can now be viewed as a series of informal blind tests that, in hindsight, underscore the pronounced influence implicit assumptions regarding the differences in wear attributes can have our interpretations. I, like many analysts, operated under the assumption that use-wear traces associated with the working of different contact materials were sufficiently recognizable that the effects of raw material variability would be minimal. The above results strongly illustrate that this is clearly not the case and that there is a serious need for increasingly systematic quantification of wear attributes and for careful consideration of how raw material physical properties affect the nature of wear accrual.

The digital image analysis concentrated on examining the invasiveness of edge and adjacent surface wear. Although proving very informative, invasiveness represents only one of many possible measures that can serve as conduits for cultural interpretation. Along with Clemex Vision's ability to significantly increase comparability of wear traces over time and from one raw material to another, it boasts the ability to evaluate a long list of physical attributes, such as edge roughness and roundness, that have the potential for providing considerable insight into patterns of wear accrual. It even has the potential to offer a more systematic means of dealing with microfracture morphology.

The application of GIS to the study of use-wear also holds great promise. With increasingly high-resolution plots of pixel gray value distributions it may be possible to more precisely define profiles of tool surface microtopography as the products of specific variable combinations. It would then become feasible to try to identify, for example, any differences between genuine use-related wear and wear generated through post-depositional processes. It may even eventually prove possible to distinguish between subsequent episodes of differing use on a single tool surface where there is only partial overlap between the respective traces.

As with digital image analysis and GIS, nanoindentation also has tremendous potential for use-wear research, particularly in terms of expanding our understanding of the relationship between raw material properties and use-wear accrual. The Hysitron Triboindenter can conduct wear tests, for example, involving the repeated parallel scratching of the surface of a sample within a pre-defined area and over a specific period of time. These tests, designed to quantify wear accrual in terms of volume of surface material lost, would undoubtedly prove extremely useful for further clarifying how tools made from different raw materials likely responded to the stresses of use. Additionally, the testing of multiple samples of the same material would considerably expand upon the results presented in Chapter 7 regarding the inherent variability of a given raw material and its physical properties.

These avenues of research, along with geological and chemical analyses of lithic raw materials, have the potential for making at least the partial re-construction of tool life histories a more attainable goal. All of this potential is, of course, dependent on the increasingly rigorous statistical evaluation of resulting data. Such future applications can collectively serve as an increasingly reliable basis for generating inferences about tool use behaviour in particular and past cultural dynamics in general.

Conclusions

At the beginning of this dissertation three questions were posited:

1) How does the role of raw material in use-wear formation affect assessment of use intensity?
2) What insights might we gain from such research regarding the respective roles of different activities in larger subsistence strategies?
3) What implications does such research have for future studies dealing with the effects of raw material type on chipped stone tool life histories and for lithic analysis in general?

In response to the first question, raw material type plays a key role in rates of wear accrual, and differences between materials clearly need to be considered in any evaluation of the intensity of use. This leads directly into the second question as the ability to assess use intensity systematically through digital image analysis opens the door to further refining our understanding of different subsistence strategies and the articulation of their various components. Finally, regarding the larger implications for lithic analysis, confirmation that raw material type can indeed significantly affect wear development and influence rates of tool edge attrition, strongly suggests that using different raw materials likely also resulted in different discard rates for shorter-term use tools and repair rates for longer-term use implements. The results of this study demonstrate the central role of raw material physical properties in determining the extent of use-related stone tool reduction both within and between recognized material categories. Further, they show that not only are shorter-term use implements viable subjects for use-wear analysis, but that any lithic analysis must incorporate the reality that these artifacts underwent constant reduction throughout their entire life histories, not just during manufacture.

While more research is needed on a number of fronts, examining the physical effects of performing different subsistence-related tasks on tool edges and surfaces made from four different raw materials has begun to reveal patterning in the relationship between material type and rates of wear accrual. As our understanding of these patterns on shorter-term use tools evolves, a firmer basis for interpretation will develop for assessing the more complex life histories of longer-term use implements. These developments will allow for greater sophistication in our reconstructions of lithic technological traditions and the subsistence strategies they served to promote.

The data generated through both digital image and GIS analyses, although very telling in their own right, required further explication. This is where nanometer-scale hardness testing comes into play. Most crystalline silica is characterized by a hardness value of seven on the qualitative Moh's scale, but the results described in Chapters Five and Six demonstrate that from one variety to another significant differences exist and can be detected. A more thorough understanding of differences in the physical properties of materials and how they affect wear development is essential to forming more reliable interpretations of tool function. This is particularly critical when dealing with a lithic archaeological record comprised of several different raw materials like that seen on FA2-13. The differences between the four materials considered here influenced the development of prehistoric wear traces to the degree that extent of wear alone cannot be used to determine tool function, much less use intensity.

The results of nanoindenter hardness tests highlight the inherent complexity of the interaction between tool and worked material surfaces during use and emphasize the need to avoid broad generalizations regarding how certain wear attributes are diagnostic of only certain activities. They also suggest that in addition to differences between material types we need to consider the possible effects of inherent variability within a single material type. The indentation of each sample under different loads at each of ten different surface locations provided data representative of both the samples as wholes and of their internal variability. While quantifiable differences between the four materials were found, the results also highlighted the fact that none of these materials is perfectly homogeneous. These findings, along with the results of the wear analyses, demonstrate that a given tool does not accrue wear evenly across its entire surface. This is an important consideration when interpreting wear traces in behavioural, and ultimately cultural, terms.

However, hardness is only part of the equation for the relationship between material properties and wear accrual rates. Micro-topographic roughness or surface heterogeneity also plays an important part in how wear develops. Along with hardness data the Triboindenter tests yielded information regarding sample surface roughness that offers some preliminary insight into how respective surface characteristics may influence wear accrual over time. These data indicate that YSW is the least heterogeneous as it exhibits minimal microtopographic variability. BB is the most heterogeneous, and SJF and MUG are intermediate.

Both material hardness and surface heterogeneity directly influence rates of wear formation and the results detailed in the preceding chapters illustrate clearly that the relationship between these two properties is quite complex. The hardness data generated demonstrate that wear will typically develop more quickly the softer a material is, but that this tendency is often mitigated by material heterogeneity in the form of surface roughness. The relatively hard YSW's surface homogeneity helped to promote the development of wear, whereas BB's relative softness was tempered by its more irregular surface characteristics.

The last forty years have seen considerable progress in understanding wear dynamics in both archaeological and material science terms. Part of these developments has involved increasing methodological overlap between these two fields of research, but as the present study can attest, a great deal more work still awaits if either discipline is to realize the full potential of this relationship. Materials science can benefit from greater insight into the complex dynamics of wear generation on heterogeneous materials and archaeology can continue to develop more reliable methods of assessing archaeological wear traces once the influence of the physical properties of raw material is more fully understood.

Theoretical Considerations and Future Directions

To properly contextualize this dissertation and its findings some commentary on its ideological underpinnings and future implications is required. Regarding the former, and as mentioned in the introduction, the concept of reduction needs to be expanded to include all stages of tool life histories. Greater ideological flexibility can and should be applied to many aspects of traditional material culture theory. Any attempt to reconstruct prehistoric behaviour patterns via analysis of stone tools demands that we as anthropologists and archaeologists consider not only each artifact on its own terms but also in relation to other prehistoric materials and to the socio-cultural system responsible for their creation.

Analogous to expanding the concept of reduction to include post-production stages of tool life histories, the notion of use and use-wear should be similarly broadened. During manufacture, a core is used to generate blanks for subsequent tool production, and then a blank is used to generate a finished tool form designed with a particular task in mind. These uses can be described as being preparatory in nature, as compared to employing a finished tool to complete a specific subsistence-related task. Recognition of preparatory, as well as practical, use of lithic technology and the relations between them can improve our ability to identify and define the processes behind the objects we study. In order to interpretively re-animate the archaeological record we need to perceive prehistoric material cultures as sets of complexly inter-related elements representative of past lifeways. It is the explication of these relations that is the ultimate goal of both archaeologist and anthropologist alike.

The perspective outlined thus far can, in the future, be brought to bear on other longstanding debates in lithic analysis. The problem of equifinality has and continues to be one of the primary limiting factors on experimental studies and archaeological interpretation as a whole. Experimental results in particular are restricted by an inability to more conclusively differentiate between two or more equally viable inferences. The viability of a given conclusion is, of course, based on the extent of our understanding of technological variability. If we can develop methodologies that permit us to piece together tool life histories, then we can begin to evaluate inference viability more critically. The most direct approach currently available to us is clearly refitting studies, but matters of practicality render this method untenable with regards to practical use-related reduction. Thus the kind of research described in this dissertation represents a first step towards developing a means of more directly evaluating reduction during the second half of tool life histories. If we are able to at least partially reconstruct these sequences, using both intra- and inter-category relations as basic building blocks, we will then be able to further reduce the number of interpretive possibilities, thus sharpening our perceptions about the prehistoric past.

On a larger scale, several ongoing debates in archaeology can also be re-addressed. Once the kinds of relations discussed above become accessible to analysts, they can be used to help gauge patterns of culture change. Technological change characterizes most prehistoric transitional periods, not the least of which being the complex shift to agriculture from a complete reliance on hunting and gathering. This change in subsistence strategy necessitated both the modification of existing tools and the development of new technologies. The increasing demand for sickle blades may manifest itself in patterns of wear accrual and in the nature of the life histories of these tools. Similarly, a decrease in exploitation of traditional resources, whether by choice or necessity, and/or changes in processing methodologies may be reflected in changes in pre-existing tool reduction trajectories. Through a better understanding of smaller scale technological change, a clearer picture of larger scale societal change can begin to emerge.

Given the present study's focus on raw material variability and its influence on stone tool life histories, the implications for lithic resource studies are of particular importance. On the most fundamental of levels, the very notion of raw material 'types' and their analytical utility is questioned by the results presented here. Clemex and GIS analyses of both experimental and archaeological wear traces amply demonstrate that any given raw material type can vary in how it responds to the application of force in the context of practical use. While the two sets of experimental dry hide scraping tools behaved in generally similar ways, noticeable differences were observed. This within-type variability was further documented by the nanoindenter hardness tests that yielded varying hardness values for each material as a function of the location of the indentation. As with typology in general, recognition of raw material types can often be interpretively problematic (e.g. Warren, 1967; see chap 3 for more refs). Despite the necessity of some basic organizing principle, typological distinctions must be tempered with a thorough appreciation of the inherent variability of material culture and the resources used in its creation.

Most resource studies share the principle aim of identifying the geological source(s) of materials contained within a given material culture. While this is certainly critical to any understanding of resource acquisition and use, it is only one piece of a larger cultural puzzle. No one would dispute the relevance of source location and accessibility to discerning patterns of resource use, but often a number of raw material types meet most practical requirements, leaving a gap in our knowledge regarding the choices made by prehistoric peoples.

The natural properties within and between different varieties of stone, especially their fracture characteristics, likely influenced which stones were ultimately selected. However, other properties such as hardness, brittleness, and durability would have affected rates of wear development, repair, and material exhaustion. This, in turn, would have had a direct bearing on demand for additional raw material. The constraints placed on this demand by available supply have serious implications for the typological ordering of stone tool assemblages. Whether one is dealing with reduction trajectories, artifact categories, or individual object attributes, typological debates abound. Following data acquisition, the first step of any artifact analysis is organizing the material to facilitate detailed assessment and interpretation. While this is a necessary precursor to furthering our collective understanding, it also serves as something of a limiting factor. Although recognition of artifact types is important for constructing culture chronologies used to identify broad temporal and spatial patterning, the conceptual separation of individual objects of material culture restricts our ability to recognize and assess smaller scale relations between them. Just as lithics are a physically reductive technology, systems of classification are reductive on a conceptual level.

Despite the widely recognized fact that typologies are primarily organizational frameworks that incorporate relatively limited inferences about the artifacts they describe, they still exert a strong influence over our perceptions of prehistoric material culture and the people that produced it. Given this, the simple act of designating a particular artifact as being a member of a discrete type places certain parameters on subsequent interpretation. Because such designations are almost always based on the condition of an artifact upon recovery, most recognized types are defined solely according to the final stage of a tool's life history. Since this represents but a fraction of what these implements potentially have to tell us about the prehistoric past, traditional 'types' at best can only provide a brief glimpse into the behaviours that produced the archaeological record.

Invoking a more dynamic model of lithic technology in an effort to gain greater insight into tool using behaviour, and thus cultural variability over time and space, requires that we expand the interpretive purview of standard analytical practice to include not only recognition of different artifact forms but of the relations that likely obtain between them. Our sights should be set on the inferential articulation of material remains, not simply their identification and enumeration. While most lithic analysts will readily agree, this perspective has yet to establish itself as an analytical mainstay within the discipline. Several authors, including Goodyear (1974) and Hoffman (1985) have incorporated this point of view into their research, but such studies remain relatively few and far between. Recognition of the dynamic nature of lithic technology, and of material culture in general, should be foundational to all analyses to allow for more realistic interpretations of cultural variability and culture change.

One other aspect of this study requires some brief discussion. Given the previously stated interest in greater terminological and therefore analytical inclusiveness it is only logical to regard other analytical constructs in a similar manner. Use-wear analysis has almost exclusively been restricted to post-production activities. As discussed above, the concept of use can and should be expanded to encompass all stages of tool life histories, but before this can be done we need to first improve our understanding of wear accrual patterns and the various agents that affect them. Of particular interest in the present study are interpretations of use intensity given the effects of raw material type. The intensity or frequency of use will clearly affect wear rates, but this relationship must also be understood in conjunction with the influence of raw material variability.

It has often been noted that poorly developed wear is intrinsically difficult to assess in terms of the activity that produced it (e.g. Keeley, 1980; Vaughan, 1985). The corollary to this is that as wear accrues it generally becomes more distinctive. Given the potential for misinterpretation where more weakly developed traces are concerned, it is vital that we understand how wear develops as a function of time, as well as raw material type. By monitoring interaction between these two variables, while approximating prehistoric tool use behaviour, we can significantly further our efforts to more fully understand archaeological wear patterns, on their own terms and as indicators of larger cultural trends.

While very informative, SEM can be a costly and time-consuming enterprise. Also, given the nature of a typical SEM sample holder, restrictions are placed on the size of tool that can be scanned and the position in which it can be held within the scanning chamber. Optical microscopy thus remains the more practical option when it comes to analyzing entire assemblages of stone tools. The results presented in this dissertation highlight the advantages of SEM but also have the potential to further systematize the optical approach. Using SEM to refine our understanding of the differences in rates of wear accrual as a function of raw material, activity type and time can serve to enhance the interpretive potential of optical microscopy. SEM has helped to clarify which use-wear attributes are of greater interpretive value and thus can be considered most effectively using optical techniques that do not require significant investments of time and money. Table 8.1 summarizes the patterns of use-wear accrual documented in this study. Following confirmation by additional experimentation, these findings can be used as something of a template or key for subsequent optical use-wear analyses involving these raw materials and either shorter- or longer-term use technologies.

Although the focus here has been on shorter-term use implements, the underlying method and theory applies equally to their longer-term counterparts. The kind of research carried out by Goodyear (1974), Hoffman (1985) and Shott (1995a) can be further enhanced by a clearer understanding of the role raw material variability plays in the direction tool life-histories ultimately take. In Chapter One the evolution of the present study was traced back to my Masters thesis and the initial raising of the question of raw material type influence on post-production or practical tool use and maintenance. My MA research revealed trends in use-related reduction among late prehistoric Huron projectile points and end scrapers, but left the role of raw material variability in generating these trends unexplored.

The research presented in the preceding chapters was designed to address this issue in such a way as to make its methods applicable to as wide a range of technologies as possible. Shorter-term use tools have served and can continue to serve as an ideal foundation for refining our understanding of raw material variability. Once the basic dynamics of tool surface/contact material interactions are better understood in the context of less complex tool life histories, the more involved nature of longer-term use technologies can begin to be reconstructed. This would entail, for example, detailed examinations of both production and use-related reduction strategies through quantification of a full range of core attributes (e.g. Binford and Quimby, 1963; Leblanc, 1992) and retouch characteristics on finished tools (e.g. Kuhn, 1990; Clarkson, 2002) respectively. Data collection in this regard for the FA2-13 assemblage has already commenced and will form part of the next stage of analysis in an ongoing program of research that will build on the results presented in this dissertation.

A more inclusive and conceptually unrestrictive approach to analyzing lithic technology is absolutely essential for learning about the prehistoric past in as objective

	Dry Hide	Fresh Hide	Juniper Wood
SJF	**EM**: Most pronounced edge rounding after 10 min, but decreases over time **OI**: Least invasive after 30 min and 2nd least invasive after 60 min; least homogeneous wear	**EM**: 2nd least pronounced edge rounding, increasing from 10 to 30 min and decreasing after 60 min **OI**: No invasive wear after any of the stages of the experiment	**EM**: Slight edge attrition only after 60 min **OI**: No invasive wear after any of the stages of the experiment
BB	**EM**: Minimal edge rounding increasing significantly only after 60 min **OI**: Least invasive after 10 and 60 min, 2nd least invasive after 30 min; 2nd least homogeneous wear	**EM**: Least pronounced edge rounding, increasing only slightly over time **OI**: No invasive wear after any of the stages of the experiment	**EM**: Slight edge attrition after 30 and 60 min **OI**: Least invasive wear after 30 min, 2nd most after 60 min; Least homogeneous wear, less than scraping hides
YSW	**EM**: Minimal edge rounding that increases significantly after 30 min and decreases after 60 **OI**: Most invasive after 10 and 60 min, 2nd most invasive after 30 min; Most homogeneous wear	**EM**: 2nd most pronounced edge rounding although still minimal, developed microfarctures after 10 min **OI**: Most invasive wear after all stages of the experiment; Most homogeneous wear but less than dry hide	**EM**: Extensive micro-fracturing **OI**: Most invasive wear after all stages of the experiment; most homogeneous wear, less than scraping hides
MUG	**EM**: Most pronounced edge rounding, increasing from 10 to 30 min and decreasing after 60 **OI**: 2nd most invasive after 10 and 60 min, most invasive after 30 min; 2nd most homogeneous wear	**EM**: Most pronounced edge rounding, increasing over time **OI**: 2nd most invasive wear after 10 and 60 min, all wear lost after 30 min due to edge collapse; 2nd most homogen-eous wear but less than dry hide	**EM:** Slight edge attrition after all stages of the experiment **OI**: 2nd most invasive wear after 10 and 30 min, 2nd least invasive after 60 min due to edge collapse; 2nd most homogeneous wear, less than scraping hides

Table 8.1: Summary of use-wear characteristics by raw material and activity type (EM = Edge Modification, OI = Overall Invasiveness).

a manner as possible. If we truly wish to move beyond straightforward classification and enumeration to more dynamic interpretations of tool using behaviour, we must learn to see stone tools as the remarkably malleable medium of material culture they are. Only when their malleability is recognized will their potential as a detailed record of cultural change be realized and a fuller appreciation of the people behind them be gained.

REFERENCES CITED

Abbott, W. J. L.
1914 Flint Fracture. *Nature*, 94: 198.

Adams, J. E.
1976 Chert and Flint. *Texas Archaeology* 20(3): 6-9.

Adams, William Y. and Ernest W. Adams
1991 *Archaeological Typology and Practical Reality: A Dialectical Approach to Artifact Classification and Sorting.* Cambridge University Press, Cambridge.

Adovasio, James M.
1993 The Ones that Will Not Go Away: A Biased View of Pre-Clovis Populations in the New World. In *Kostenki to Clovis: Upper Palelithic-Paleo-Indian Adaptations,* edited by Olga Soffer and N. D. Praslov, pp. 199-218. Plenum Press, New York.

Adovasio, James M., J. Donahue, and R. Stukenrath
1990 The Meadowcroft Rockshelter Radiocarbon Chronology 1975-1990. *American Antiquity* 55: 348-354.

Ahler, S. A. and R. C. Christensen
1983 *A Pilot Study of Knife River Flint Procurement and Reduction at Site 32DU508, a Quarry and Workshop Location in Dunn County, North Dakota.* Contribution No. 186. Department of Anthropology and Archaeology, University of North Dakota, Grand Forks.

Amick, Daniel S.
1980 *A Preliminary Assessment of Chert Resources in the Columbia Reservoir, Maury and Marshall Counties, Tennessee.* Paper presented at the 37th Annual Southeastern Archaeological Conference, New Orleans.

Amick, Daniel S., Raymond P. Mauldin, and Lewis R. Binford
1989 The Potential of Experiments in Lithic Technology. In *Experiments in Lithic Technology*, edited by D. S. Amick and R. P. Mauldin, pp. 1-14, BAR International Series, British Archaeological Reports, No. 528, Oxford, U.K.

Amick, Daniel S., Raymond P. Mauldin, and Steven A. Tomka
1988 An Evaluation of Debitage Produced by Experimental Bifacial Core Reduction of a Georgetown Chert Nodule. *Lithic Technology*, 17: 26-36.

Ammerman, Albert J. and Marcus W. Feldman
1974 On the Making of an Assemblage of Stone Tools. *American Antiquity,* 39: 610-616.

Andrefsky, William Jr.
1994 Raw-Material Availability and the Organization of Technology. *American Antiquity* 59(1): 21-34.

Ascher, R.
1961a Analogy in Archaeological Interpretation. *Southwestern Journal of Anthropology*, 17: 317-325.

1961b Experimental Archaeology. *American Anthropologist*, 63: 793-816.

Bahn, P. G.

1987 Getting Blood from Stone Tools. *Nature*, 330: 14.

Bamforth, D.B.

1990 Settlement, Raw Material, and Lithic Procurement in the Central Mojave Desert. *Journal of Anthropological Archaeology* 9: 70-104.

Barbieri, Joseph A.

1937 Technique of the Implements from Lake Mohave. In *The archaeology Of Pleistocene Lake Mohave: A Symposium*, Southwest Museum Papers 11: 99-107.

Barnhart, E.

1992 Lithic Procurement at Yellow Jacket, Colorado: A Study of Points, Drills, and Flakes. *Southwestern Lore* 58(4): 24-30.

Barnes, A. S.

1932 Modes of Prehension of Some Forms of Upper Paleolithic Implements. *Prehistoric Society of East Anglia, Proceedings*, 7: 43-56.

1939 The Differences Between Natural and Human Flaking on Prehistoric Flint Implements. *American Anthropologist*, 41: 99-112.

Bartlett, K.

1935 Prehistoric Mining in the Southwest. *Museum of Northern Arizona Notes* 7(10): 41-44.

1942 A Primitive Stone Industry of the Little Colorado Valley, Arizona. *The Plateau* 14(3): 266-268.

Barton, H., R. Torrence, and R. Fullagar

1998 Clues to Stone Tool Function Re-Examined: Comparing Starch Grain Frequencies on Used and Unused Obsidian Artefacts. *Journal of Archaeological Science*, 25: 1231-1238.

Bauche, Rolf

1986 Die Anwendung von Rauheitsmessungen bei der Untersuchung von Neolithischen Mahl- und Schleifsteinen. In *Early Man News, 9/10/11, Newsletter for Human Palecology, Part I*, edited by Linda R. Owen and Guenther Unrath, pp. 51-67. Tübingen.

Baumler, Mark F.

1995 Principles and Properties of Lithic Core Reduction: Implications for Levallois Technology. In *The Definition and Interpretation of Levallois Technology*, edited by Harold L. Dibble and Ofer Bar-Yosef. Monographs in World Archaeology No. 23, pp. 11-23. Prehistory Press, Madison, Wisconsin.

Bayman, James M. and M. Steven Shackley

1999 Dynamics of Hohokam obsidian circulation in the North American Southwest. *Antiquity* 73: 836-845.

Beck, C. and G. T. Jones

1990 Toolstone Selection and Lithic Technology in Early Great Basin Prehistory. *Journal of Field Archaeology* 17: 283-299.

Beckett, Patrick, H. and Richard S. MacNeish

1994 The Archaic Chihuahua Tradition of South-Central New Mexico and

Chihuahua, Mexico. In *Archaic Hunter-Gatherer Archaeology in the American Southwest,* edited by Bradley J. Vierra, Contributions in Anthropology, 13(1), pp. 335-371. Eastern New Mexico University, Portales.

Bell, R. E., and R. S. Hall

1953 Selected Projectile Point Types of the United States. *Oklahoma Anthropological Society Bulletin,* No. 1, pp. 1-16.

Berg, Caryn M.

1993 *Using Microwear Analysis to Determine Stone Tool Use at Elden Pueblo.* Unpublished Master's Thesis, Department of Anthropology, Northern Arizona University, Flagstaff.

Bertram, Jack B.

1997c FA2-13 Faunal Remains. In *Archaeology of the Farmington Sector of the Elena Gallegos Project*, edited by Joseph A. Tainter, pp. 241-262, Heritage Resources Management Report No. 16, USDA Forest Service Southwestern Region.

Bernard-Shaw, Mary

1983 Stone Tool Assemblage of the Salt-Gila Aqueduct Project Sites. In *Hohokam Archaeology Along the Salt-Gila Aqueduct Central Arizona Project, Vol. 8: Material Culture,* edited by L. S. Teague and P. L. Crown, pp. 373-443. Archaeological Series No. 150. Tuscon: Arizona State Museum.

Bettinger, Robert L.

1978 Alternative Adaptive Strategies in the Prehistoric Great Basin. *Journal of Anthropological Research*, 34: 27-46.

Binford, Lewis R.

1967a Smudge Pits and Hide Smoking: The Use of Analogy in Archaeological Reasoning. *American Antiquity*, 32(1): 1-12.

1968b Theory and Method. In *New Perspectives in Archaeology*, edited by S. R. Binford and L. R. Binford, pp. 1-3, Chicago: Aldine.

1979 Organization and Formation Processes: Looking at Curated Technologies. *Journal of Anthropological Archaeology* 35(3): 255-273.

1981b *Bones: Ancient Men and Modern Myths.* New York, Academic Press.

1982b Objectivity, Explanation, and Archaeology 1980. In *Theory and Explanation in Archaeology*, edited by C. Renfrew, M. J. Rowlands, and B. Segraves-Whallon, New York, Academic Press.

Binford, Lewis. R. and G. I. Quimby

1963 Indian Sites and Chipped Stone Materials in the Northern Lake Michigan Area. *Fieldiana Anthropology* No.36: 277-307.

Bisson, M. S.

2001 Interview with a Neanderthal: An Experimental Approach for Reconstructing Scraper Production Rules, and Their Implications for Imposed Form in Middle Paleolithic Tools. *Cambridge Archaeological Journal*, 11: 165-184.

Bixby, Lawrence B.

1945 Flint Chipping. *American Antiquity*, 10: 353-361.

Blain, H.D. & J.R. Davis
1984 *An Archaeological Site Potential Map of Australia.* Technical Memorandum 84/28. Canberra: CSIRO Institute of Biological Resources, Division of Water and Land Resources.

Bloomer, W. W.
1954 Reduction Assemblage Models in the Interpretation of Lithic Technology at the Tosawihi Quarries, North-Central Nevada. *Journal of California and Great Basin Anthropology* 13(2): 204-216.

Bockley-Fisher, G. M.
1990 *Raw Material Resources and Lithic Distribution: Interaction and Exchange in the Galisteo Basin, NM, A.D. 1400-1600.* Unpublished MA Thesis, New Mexico State University, Las Cruces.

Bodner, D., S. Weisman and J. Dixon
n.d. *A Chronology of Projectile Points in Southwestern Ontario During Prehistoric Times.* Unpublished Manuscript, London Museum of Archaeology, The University of Western Ontario.

Boëda, Eric
1995 Levallois: A Volumetric Construction, Methods, a Technique. In *The Definition and Interpretation of Levallois Technology*, edited by Harold L. Dibble and Ofer Bar-Yosef. Monographs in World Archaeology No. 23, pp. 41-68. Prehistory Press, Madison, Wisconsin.

Bonney, Rachel A.
1971 *A Preliminary Analysis of the Lithic Artifacts from Arroyo Hondo.* Ms., School of American Research, Santa Fe, New Mexico.
1972 *Arroyo Hondo 1972 Lithic Analysis: Typology, Distribution, and Functions.* Ms., School of American Research, Santa Fe, New Mexico.

Bonnichsen, Robson
1968a Note 1 from the Experimental Laboratory: Experimentation as a Means of Constructing Meaningful Classifications of Stone Artifacts. *Archaeological Society of Alberta Newsletter*, 17: 4-10.
1977 Models for Deriving Cultural Information From Stone Tools. *Archaeological Survey of Canada. National Museum of Man Mercury Series, Paper No. 60,* Ottawa.

Bordes, Francois
1952 A Propos des Outils à Bord Abattu: Quelques Remarques. *Bulletin de la Societe Prehistorique Francaise*, 49: 645-647.
1955 Observations sur la Note de M. H. Kelley sur la Technique de Taille "Levalloisienne". *Bulletin de la Societe Prehistorique Francaise*, 52: 113-114.
1961a *Typologie du Paléolithique Ancien et Moyen.* Bordeaux: Delmas.
1961b Mousterian cultures in France. *Science*, 134: 803-810.
1968 *The Old Stone Age.* Translated by J. E. Anderson. New York: World University Library.
1969a Reflections on Typology and Techniques in the Palaeolithic. *Arctic Anthropology*, 6: 1-29. (Translated by John Kelley and Jacques Cinq-

Mars from *Quartar*, 18: 25-55 [1967])
1970 Observations Typologiques et Techniques sur le Périgordien Supérieur de Corbiac (Dordogne). Bulletin de la Societe Prehistorique Française, 67:105-113.

Bordes, Francois and Don E. Crabtree
1969 The Corbiac Blade Technique and Other Experiments. *Tebiwa*, 12(2): 1-21.

Bourlon, M.
1911 Essai de Classification des Burins. *Revue Anthropologique*, 21: 267-278.

Bradbury, A. P. and P. J. Carr
1999 Examining Stage and Continuum Models of Flake Debris Analysis: An Experimental Approach. *Journal of Archaeological Science*, 26: 105-116.

Bradley, Bruce A.
1993 Paleo-Indian Flaked Stone Technology in the Northern American High Plains. In *Kostenki to Clovis: Upper Paleolithic-Paleo-Indian Adaptations,* edited by Olga Soffer and N. D. Praslov, pp. 251-262. Plenum Press, New York.
1997 General Observations of Flaked Stone Technology. In *Ceramics, Lithics, and Ornaments of Chaco Canyon, Vol. 2,* edited by F. J. Mathien, pp. 698-699. Publications in Archaeology 18G. Chaco Canyon Studies, National Park Service, Santa Fe, New Mexico.

Brink, John W.
1978 *An Experimental Study of Microwear Formation on Endscrapers.* National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper No. 83. Ottawa.

Brown, G. M.
1982a *Lithic Exchange and Production on Anderson Mesa, North-Central Arizona.* Unpublished MA thesis, Arizona State University, Tempe.
1982b *Archaeological Investigations at Yankee Target, a Prehistoric Chert Quarry on the Arizona Strip, Northwest Mohave County, Arizona.* Research Series 3. Abajo Archaeology, Bluff (Utah).
1996 Embedded and Direct Lithic Resource Procurement Strategies on Anderson Mesa. *Kiva* 56(4): 359-384.

Bryan, K.
1950 *Flint Quarries-The Source of Stone Tools and, at the Same Time, the Factories of the American Indian.* Paper 3, Peabody Museum of American Archaeology and Ethnology, Cambridge.

Bye, Robert A. Jr.
1972 Ethnobotany of the Southern Paiute Indians in the 1870s: with a Note on the Early Ethnobotanical Contributions of Dr. Edward Palmer. In *Great Basin Cultural Ecology: A Symposium*, edited by Don D. Fowler, pp. 87-104. Desert Research Institute Publications in the Social Sciences 8. Reno, Nevada.

Callahan, Errett

1976a Time and Flint Needed to Acquire Secondary Thinning Bifacial Reduction Skills. *Newsletter of Lithic Technology*, 5(3): 26-27.

1979 The Basics of Biface Knapping in the Eastern Fluted Point Tradition: A Manual for Flintknappers and Lithic Analysts. *Archaeology of Eastern North America*, 7: 1-180.

Cameron, C. M.

1984 A Regional View of Chipped Stone Raw Material Use in Chaco Canyon. In *Recent Research on Chaco Prehistory*, edited by W. J. Judge and J. D. Schelberg, pp. 137-153. Reports of the Chaco Center #8. National Park Service, U. S. Department of the Interior, Albuquerque.

1987 Chipped Stone Tools and Cores: An Overview of the 1982-1983 Field Seasons. In *Prehistoric Stone technology on Northern Black Mesa, Arizona*, edited by William J. Parry and Andrew L. Christenson, pp. 95-141. Center for Archaeological Investigations, Southern Illinois University at Carbondale. Occasional Paper No. 12.

1997 The Chipped Stone of Chaco Canyon, A.D. 500-1200. In *Recent Research on Chaco Prehistory*, Vol. 2, edited by F. J. Mathien, pp. 531-658. Publications in Archaeology 18G. Chaco Canyon Studies, National Park Service, Santa Fe.

2001 Pink Chert, Projectile Points, and the Chacoan Regional System. *American Antiquity* 66(1): 79-101.

Cameron, C. M. and R. L. Sappington

1984 Obsidian Procurement at Chaco Canyon, A.D. 500-1200. In *Recent Research on Chaco Prehistory*, edited by W. J. Judge and J. D. Schelberg, pp. 137-152. Reports of the Chaco Center #8. National Park Service, U. S. Department of the Interior, Albuquerque.

Camilli, E. L.

1988 Lithic Raw Material Selections and Use in the Desert Basins of South-Central New Mexico. *The Kiva* 53(2): 147-163.

Carmichael, D. L.

1984 Lithic Procurement Activities near Clayton, New Mexico. In *Philmont Conference on the Archaeology of Northeastern New Mexico*, edited by C. J. Condie, pp. 169-183. New Mexico Archaeological Council, Albuquerque.

1990 GIS Predictive Modelling of Prehistoric Site Distributions in Central Montana. In *Interpreting Space: GIS and Archaeology*, edited by K. M. S. Allen, S.W. Green & E.B.W. Zubrow, pp. 216-225. Taylor & Francis, London.

Carr, P. J. and A. P. Bradbury

2001 Flake Debris Analysis, Levels of Production, and the Organization of Technology. In *Lithic Debitage: Context, Form, Meaning*, edited by William Andrefsky Jr. pp. 126-146. The University of Utah Press, Salt Lake City.

Cattaneo, C., K. Gelsthorpe, R. Phillips, and R. J. Sokal
1993 Blood Residues on Stone Tools: Indoor and Outdoor Experiments. *World Archaeology*, 25: 29-43.

Chadwick, A.J.
1978 A Computer Simulation of Mycenean Settlement. In *Simulation Studies in Archaeology*, edited by Ian Hodder, pp. 47-57. Cambridge University Press, Cambridge.

Channen, E.R. and N.D. Clarke
1965 The Copeland Site: A Precontact Huron Site in Simcoe County, Ontario. *Anthropology Papers, National Museum of Canada, Number 8*, Ottawa

Chapman, Richard C.
1977 Analysis of Lithic Assemblages. In *Settlement and Subsistence along the Lower Chaco River: The CGP Project,* edited by C. A. Reher, pp. 371- 452. Office of Contract Archaeology, University of New Mexico, Albuquerque.

1982a Projectile Points, Chronology and Cultural Tradition upon the Lower Rio Puerco. In, *Inventory Survey of the Lower Hidden Mountain Flood-pool, Lower Rio Puerco Drainage, Central New Mexico,* edited by P. L. Eidenbach, pp. 223-235. Human Systems Research, Inc., Tularosa.

1982b Dating Archaeological Sites with Lithic Manufacturing Debris. In, *Inventory Survey of the Lower Hidden Mountain Flood-pool, Lower Rio PuercoDrainage, Central New Mexico,* edited by P. L. Eidenbach, pp. 235-287. Human Systems Research, Inc., Tularosa.

Cheynier, A. and A. S. Barnes
1937 Lames à Section Triangulaire et les Pièces à Crête. *Congrès Préhistorique de France, XIIe Session 1936,* p. 630-637.

Christenson, Andrew L.
1987a The Prehistoric Tool Kit. In, *Prehistoric Stone Technology on Northern Black Mesa, Arizona,* edited by William J. Parry and Andrew L. Christenson, pp. 43-94. Center for Archaeological Investigations, Southern Illinois University at Carbondale, Occasional Paper No. 12.

1987b Projectile Points: Eight Millennia of Projectile Change on the Colorado Plateau. In, *Prehistoric Stone Technology on Northern Black Mesa, Arizona,* edited by William J. Parry and Andrew L. Christenson, pp. 143-198. Center for Archaeological Investigations, Southern Illinois University at Carbondale, Occasional Paper No. 12.

Church, F. S. and J. T. Hack
1939 An Exhuned Erosion Surface in the Jemez Mountains, New Mexico. *Journal of Geology*, 48: 613-629.

Church, Tim
1994 *Lithic Resource Studies: A Sourcebook for Archaeologists.* Lithic Technology Special Publication No. 3. Department of Anthropology, University of Tulsa, Oklahoma.

Clarkson, Chris
2002 An Index of Invasiveness for the Measurement of Unifacial and Bifacial Retouch: A Theoretical, Experimental and Archaeological Verification.

Journal of Archaeological Science, 29: 65-75.
Coffey, B.
1994 The Chemical Alteration of Microwear Polishes: An Evaluation of the Plisson and Mauger Findings Through Replicative Experimentation. *Lithic Technology*, 19: 88-92.
Coffin, R. G.
1936 *Northern Colorado's First Settlers.* Ft. Collins: Colorado State University.
1951 Sources and Origin of Northern Colorado Artifact Materials. *Southwest Lore* 17(1): 2-6.
Coles, J.
1967 Experimental Archaeology. *Proceedings of the Society of Antiquaries Scotland*, 99: 1-20.
1973 *Archaeology by Experiment.* Charles Scribner's Sons, New York.
1979 *Experimental Archaeology.* Academic Press, London, England.
Collins, Michael B.
1975 Lithic Technology as a Means of Processual Inference. In *Lithic Technology: Making and Using Stone Tools,* edited by Earl Swanson, pp. 15-34. World Anthropology Series, Mouton Publishers, The Hague, Paris.
Cooper, L. M.
1975 A Study of Kay County Flint: Prehistoric Quarrying, Typology, and Utilization Trends. *Bulletin of the Oklahoma Archaeological Society* 23: 185-192.
Cootes, Tim
2000 Model-based Methods in Analysis of Biomedical Images. In *Image Processing and Analysis: A Practical Approach*, edited by Richard Bladock and Jim Graham, pp. 223-248. Oxford University Press, Oxford.
Copeland, Lorraine
1995 Are Levallois flakes in the Acheulian the results of Biface Preparation. In *The Definition and Interpretation of Levallois Technology*, edited by Harold L. Dibble and Ofer Bar-Yosef. Monographs in World Archaeology No. 23, pp. 171-183. Prehistory Press, Madison, Wisconsin.
Cordell, Linda
1997 *Archaeology of the Southwest, 2nd Edition.* University Museum, University of Colorado, Boulder, Colorado. Academic Press, London.
Cotterell, B. and J. Kamminga
1987 The Formation of Flakes. *American Antiquity*, 52: 675-708.
Cotterell, B., J. Kamminga, and F. D. Dickson
1985 The Essential Mechanics of Concoidal Flaking. *International Journal of Fracture*, 20: 205-221.
Coutier, L.
1929 Expériences de Taille pour Rechercher les Anciennes Techniques Paléo-lithiques. *Bulletin de la Société Préhistorique Française*, 26: 172-174.

Crabtree, Don E.
1966 A Stone-worker's Approach to Analyzing and Replicating the Lindenmeier Folsom. *Tebiwa*, 9(1): 3-39.
1967a Notes on Experiments in Flintknapping 3: The Flintknapper's Raw Materials. *Tebiwa*, 10(1): 8-24.
1967b Notes on Experiments in Flintknapping 4: Tools Used for Making Flaked Stone Artifacts. *Tebiwa*, 10(1): 60-73.
1969 A Technological Description of Artifacts in Assemblage 1, Wilson Butte Cave, Idaho. *Current Anthropology*, 10: 366-367.
1970 Flaking Stone with Wooden Implements. *Science*, 169: 146-153.
1972 An Introduction to Flintworking. In *Occasional Papers of the Idaho State University Museum,* No. 28, Pocatello, Idaho.
1974 Comments on Lithic Technology and Experimental Archaeology. In *Lithic Technology: Making and Using Stone Tools*, edited by Earl Swanson, pp. 105-114, Mouton Publishers, The Hague.
1977 The Obtuse Angle as a Functional Edge. In *Experimental Archaeology*, edited by Daniel Ingersoll, John E. Yellen, and William Macdonald, pp. 39-51, Columbia University Press, New York.

Crabtree, Don E. and B. R. Butler
1964 Notes on Experiments in flintknapping 1: Heat Treatment of Silica Materials. *Tebiwa*, 7(3): 1-6.

Crabtree, Don E. and E. L. Davis
1968 Experimental Manufacture of Wooden Implements with Tools of Flaked Stone. *Science*, 159: 426-428.

Crabtree, Don E. and R. A. Gould
1970 Man's Oldest Craft Recreated. *Curator*, 13: 179-188.

Crabtree, Don E. and E. H. Swanson
1969 Edge-ground Cobbles and Blade-making in the Northwest. *Tebiwa*, 11(2): 50-58.

Cushing, Frank Hamilton
1879 Curious Discoveries in Regard to the Manner of Making Flint Implements by the Aborigines and Prehistoric Inhabitants of America. *Engineering and Mining Journal*, 28: 91.

Davidson, T.E.
1986 Computer-Correcting Historical Maps for Archaeological Use. *HistoricalArchaeology* 20 (2): 27-37.

Davis, Emma Lou
1965 An Ethnography of the Kuzedika Paiute of Mono Lake, Mono County, California. *University of Utah Anthropological Papers* 75: 1-55, Salt Lake City, Utah.

Davis, William E.
1985 Chipped Stone Analysis. In *Anasazi Subsistence and Settlement on White Mesa, San Juan County, Utah,* edited by William E. Davis. Abajo Archaeology, Bluff Utah. University Press of America.

Davis, Zachary J. and John J. Shea
1998 Quantifying Lithic Curation: An Experimental Test of Dibble and Pelcin's Original Flake-Tool Mass Predictor. *Journal of Archaeological Science*, 25: 603-610.

Del Bene, Terry. A.
1978 Once Upon a Striation: Current Models of Striation and Polish Formation. In *Lithic Use-Wear Analysis*, edited by B. Hayden, pp. 167-177, Studies in Archaeology Series, New York: Academic Press.

Del Bene, Terry A. and William R. Branchard
1994 A Synthesis of Archaic Archaeology on the Navajo Indian Irrigation Project, Northwestern New Mexico. In *Archaic Hunter-Gatherer Archaeology in the American Southwest,* edited by Bradley J. Vierra. Contributions in Anthropology, 13(1), pp. 231-290. Eastern New Mexico University, Portales.

Derndarsky, M. and G. Ocklind
2001 Some Preliminary Observations on Subsurface Damage on Experimental and Archaeological Quartz Tools using CLSM and Dye. *Journal of Archaeological Science*, 28: 1149-1158.

Diamond, G.
1979 The Nature of So-called Polished Surfaces on Stone Artifacts. In *Lithic Use- Wear Analysis*, edited by B. Hayden, pp. 159-166, Studies in Archaeology Series, New York: Academic Press.

Dibble, H. L.
1988 Typological Aspects of Reduction and Intensity of Utilization of Lithic Resources in the French Mousterian. In *Upper Pleistocene Prehistory of Western Eurasia*, edited by H. L. Dibble and A. Montet-White, pp. 181-187, University Museum Symposium Series, Vol. 1, Philadelphia.
1995b Middle Paleolithic Scraper Reduction: Background, Clarification, and Review of Evidence to Date. *Journal of Archaeological Method and Theory*, 2: 299-368.
1997 Platform Variability and Flake Morphology: A Comparison of Experimental and Archaeological Data and Implications for Interpreting Prehistoric Lithic Technological Strategies. *Lithic Technology*, 22: 150-170.
1998 Comment on "Quantifying Lithic Curation: An Experimental Test of Dibble and Pelcin's Original Flake-Tool Mass Predictor", by Zachary J. Davis and John J. Shea. *Journal of Archaeological Science*, 25: 611-613.

Dibble, H. L. and A. Pelcin
1995 The Effect of Hammer Mass and Velocity on Flake Mass. *Journal of Archaeological Science*, 22: 429-439.

Dibble, H. L. and J. Whittaker
1981 New Experimental Evidence on the Relation Between Percussion Flaking and Flake Variation. *Journal of Archaeological Science*, 6: 283-296.

Dittert Jr. A. E.
1968 Minerals and Rocks at Archaeological Sites: Some Interpretations from Central Western New Mexico. *The Arizona Archaeologist* 3: 1-16.

Dockall, John E.
1997 Wear Traces and Projectile Impact: A Review of the Experimental and Archaeological Evidence. *Journal of Field Archaeology*, 24: 321-331.

Doyel, David E.
1984 From Foraging to Farming: An Overview of the Preclassic in the Tucson Basin. *The Kiva*, 49 (3-4): 147-165.

Dumont, J. V.
1982 The Quantification of Microwear Traces: A New Use for Interferometry. *World Archaeology*, 14: 206-217.

Dunnell, Robert C.
1971b *Systematics in Prehistory.* Free Press, New York.

Effland, R.W.
1979 Statistical Distribution Cartography and Computer Graphics. In *Computer Graphics in Archaeology*, edited by S. Upham, pp. 17-29. Anthropological Research Papers 15. Arizona State University, Tempe.

Eidenbach, Peter L.
1982 Analysis of Isolated Occurrence Data. In, *Inventory Survey of the Lower Hidden Mountain Flood-pool. Lower Rio PuercoDrainage, Central New Mexico,* edited by P. L. Eidenbach, pp. 287-304. Human Systems Research, Inc., Tularosa.

Eley, Betty E. and Peter H. von Bitter
1989 *Cherts of Southern Ontario.* Royal Ontario Museum, Toronto.

Ellis, Howard Holmes
1940 *Flint-Working Techniques of the American Indians: An Experimental Study.* Columbus: Lithic Laboratory, Department of Archaeology, Ohio State Museum.

Elsen, M. D. and J. J. Clark
1995 *The Roosevelt Community Development Study,*" Vol. 1, Anthropological Papers No. 14. Center for Desert Archaeology, Tucson.

Elston, R.G.
1986 *The Structural Analysis of Lithic Production Systems.* PhD Dissertation Washington State University, Pullman.

Elyea, Janette M.
1988 Analysis of Paleo-Indian Tools from LA 63880. In, *The Border Star 85 Survey Toward an Archeology of Landscapes,* edited by T. J. Seaman, W. H. Doleman, and R. C. Chapman, pp. 231-237. Office of Contract Archeology, University of New Mexico, Albuquerque.

Engerrand, George C.
1912 L' État Actuel de la Question des Éoliths. *Revue Générale des Sciences*, 23: 541-548.
1913 Estado Actual de la Cuestión de los Eolitos. *Boletin del Museo Nacional de Arqueologia, Historia, y Etnologia*, 2: 150-60.

Ericson, Jonathon E.
1984 Toward the Analysis of Lithic Production Systems. In, *Prehistoric Quarries and Lithic Production* edited by J. E. Ericson and B. A. Purdy, pp. 1-9. Cambridge University Press, Cambridge.

Estes, J.E., J.R. Jensen & L.R. Tinney
1977 The Use of Historical Photography for Mapping Archaeological Sites. *Journal of Field Archaeology* 4: 441-447.

Evans, Sir John
1860 On the Occurrence of Flint Implements in Undisturbed Beds of Gravel, Sand, and Clay. *Archaeologia*, 38: 280-307.

Fenega, Franklin
1953 The Weights of Chipped Stone Points: A Clue to their Functions. *Southwestern Journal of Anthropology,* 9(2): 120-138.

Findlow, F. J. and M. Bolognese
1984 Economic Aspects of Prehistoric Quarry Use: A Case Study in the American Southwest. In *Prehistoric Quarries and Lithic Production* edited by J. E. Ericson and B. A. Purdy, pp. 77-82. Cambridge University Press, Cambridge.

Fischer, A., P. Vemming Hansen, and P. Rasmussen
1984 Macro and Micro Wear Traces on Lithic Projectile Points. *Journal of Danish Archaeology*, 3:19-46.

Fitting, J. E. and L. M. Stone
1969 Distance and Utility in the Distribution of Raw Materials in the Cedar Mountains of New Mexico. *The Kiva* 34(4): 207-212.

Flenniken, J. J.
1981 *Replicative Systems Analysis: A Model Applied to the Vein Quartz Artifacts from the Hoko River Site.* Washington State University Laboratory of Anthropology Reports of Investigations, No. 59.
1984 The Past, Present, and Future of Flintknapping: an Anthropological Perspective. *Annual Review of Anthropology*, 13: 187-203.
1985 Stone Tool Reduction Techniques as Cultural Markers. In *Stone Tool Analysis: Essays in Honor of Don E. Crabtree*, edited by M. G. Plew, J. C. Woods, and M. G. Pavesic, pp. 265-276. University of New Mexico Press, Albuquerque.

Flenniken, J. J. and J. Haggarty
1979 Trampling as an Agency in the Formation of Edge Damage: An Experiment in Lithic Technology. *Northwest Anthropological Research Notes,* 13: 208-214.

Folsom, F. and George A. Agogino
1975 New Light on an Old Site: Events Leading up to the Discovery of the Folsom Type Site. *Anthropological Journal of Canada,* 13(3): 2-5.

Fonesca, J. G., J. D. Eshelby, and C. Atkinson
1971 The Fracture Mechanics of Flint-Knapping and Allied Processes. *International Journal of Fracture Mechanics*, 7: 421-433.

Fowke, G.

1891 Stone Art. *Bureau of American Ethnology Annual Report*, 13: 47-178.

1892b A Brief Description of Flint Ridge. In, *Primitive Man in Ohio.* New York.

Fowler, Catherine S.

1977 Ethnography and Great Basin Prehistory. In *Models in Great Basin Prehistory: A Symposium*, edited by Don D. Fowler, pp. 11-48. Desert Research Institute Publications in the Social Sciences 12. Reno, Nevada.

1982 Settlement Patterns and Subsistence Systems in the Great Basin: The Ethnographic Record. In *Man and the Environment in the Great Basin*, edited by David B. Madsen and James F. O'Connell, pp. 121-138. SAA Papers No. 2. Washington, D.C.

Fox, William A.

1979a An Analysis of an Historic Huron Attignawanton Lithic Assemblage. *Ontario Archaeology,* No. 32, pp. 61-88.

Frison, George C.

1979 Observations on the Use of Stone Tools: Dulling of Working Edges of Some Chipped Stone Tools in Bison Butchering. In *Lithic Use-Wear Analysis*, edited by B. Hayden, pp. 259-268. Academic Press, New York.

1989 Experimental Use of Clovis Weaponry and Tools on African Elephants. *American Antiquity*, 54: 766-784.

1993 North American High Plains Paleo-Indian Hunting Strategies and Weaponry Assemblages. In, *Kostenki to Clovis: Upper Paleolithic-Paleo-Indian Adaptations,* edited by Olga Soffer and N. D. Praslov, pp. 237-249. Plenum Press, New York.

Frison, George C. and B. A. Bradley

1980 *Folsom Tools and Technology at the Hanson Site, Wyoming.* University of New Mexico Press, Albuquerque.

Fullagar, R. L. K.

1991 The role of silica in polish formation. *Journal of Archaeological Science*, 18: 1-24.

Fullagar, R. L. K., J. Furby, and B. L. Hardy

1996 Residues on Stone Artifacts: State of a Scientific Art. *Antiquity*, 70: 740-745.

Fyfe, Ralph

2006 GIS and the Application of a Model of Pollen Deposition and Dispersal: A New Approach to Testing Landscape Hypotheses Using the POLLANDCAL Models. *Journal of Archaeological Science*, 33: 483-493.

Gaffney, V. & Z. Stancic

1994 GIS and Historical Archaeology: The Case of the Island of Hvar in Croatia. *Archeologia E Calcolatori* 5: 257-268.

Gatus, Thomas W.

1980 Chert Resources of the Lower Cumberland and Lower Tennessee River

Valleys in Western Kentucky. *Proceedings of the 37th annual Southeastern Archaeological Conference, Bulletin* 24.

Geeslin, J. H. and H. S. Chafetz
1982 Ordovician Aleman Ribbon Cherts: An Example of Silicification Prior to Carbonate Lithification. *Journal of Sedimentary Petrology*, 52: 1283-1293.

Gifford-Gonzales, D., D. P. Damrosch, D. R. Damrosch, J. Pryor and R. Thunen
1985 The Third Dimension in Site Structure: An Experiment in Trampling and Vertical Dispersal. *American Antiquity,* 50: 803-818.

Glascock, Michael D., Raymond Kunselman and Daniel Wolfman
1999 Intrasource Chemical Differentiation of Obsidian in the Jemez Mountains and Taos Plateau, New Mexico. *Journal of Archaeological Science* 26: 861-868.

Goodman, Mary Ellen
1944 The Physical Properties of Stone Tool Materials. *American Antiquity*, 9: 415-433.

Goodyear, A. C.
1974 *The Brand Site: A Techno-Functional Study of a Dalton Site in Northeast Arkansas.* Series No. 7, Fayetteville: Arkansas Archaeological Survey Research.

Goodyear, A. C., L. M. Raab, and T. C. Klinger
1979 The Status of Archaeological Research Design in Cultural Resource Management. *American Antiquity*, 43(2): 159-171.

Gossett, Cye
1982a Lithic Assemblages of the Lower Rio Puerco Valley. In, *Inventory Survey of the Lower Hidden Mountain Flood-pool. Lower Rio PuercoDrainage, Central New Mexico,* edited by P. L. Eidenbach, pp. 169-212. Human Systems Research, Inc., Tularosa.
1982b Lithic Material Types of the Lower Rio Puerco. In, *Inventory Survey of the Lower Hidden Mountain Flood-pool. Lower Rio PuercoDrainage, Central New Mexico,* edited by P. L. Eidenbach, pp. 212-222. Human Systems Research, Inc., Tularosa.

Gould, R. A.
1978 Beyond Analogy in Ethnoarchaeology. In *Explanations in Ethnoarchaeology*, edited by R. A. Gould, pp. 249-293, Albuquerque: University of New Mexico Press.
1980 *Living Archaeology*. Cambridge: Cambridge University Press.

Grace, R.
1989 *The Quantification and Computerization of Microwear Analysis*. B.A.R. International Series, British Archaeological Reports 474. Oxford: UK.
1990 The Limitations and Applications of Use-Wear Analysis. In *The Interpretive Possibilities of Microwear Analysis*, edited by B. Graslund, H. Knutsson, K. Knutsson, and J. Taffinder, pp. 9-14, Uppsala: Societas Archaeologica Upsaliensis.

Grace, R., I. D. G. Graham, and M. H. Newcomer
1985 The Quantification of Microwear Polishes. *World Archaeology*, 17: 112-120.
1987 The Mathematical Characterization of Wear Traces on Prehistoric Flint Tools. In *The Human Uses of Flint and Chert: Papers from the Fourth International Flint Symposium*, edited by G. Sieveking and M. H. Newcomer, pp. 63-69, Cambridge: University of Cambridge Press.

Graham, Jim
2000 Pattern Recognition: Classification of Chromosomes. In *Image Processing and Analysis: A Practical Approach*, edited by Richard Bladock and Jim Graham, pp. 111-152. Oxford University Press, Oxford.

Gramly, R. M.
1980 Raw Material Source Areas and "Curated" Tool Assemblages. *American Antiquity* 45(4): 823-833.

Green, M.
1984 The Relationship of Source Distance to Conservation of Chipped Stone Raw Materials. In *Papers on the Archaeology of Black Mesa, Arizona*, pp. 171-188. Southern Illinois University Press, Carbondale.
1985 *Chipped Stone Raw Materials and the Study of Interaction.* Occasional Paper No. 11, Center for Archaeological Investigations, Southern Illinois University at Carbondale.
1986 The Distribution of Chipped Stone Raw Materials at Functionally Non-equivalent Sites. In *Spatial Organization and Exchange: Archaeological Survey on Northern Black Mesa*, edited by S. Plog, pp. 143-168. Southern Illinois University Press, Carbondale.

Greiser, S. T.
1982 A Preliminary Statement about Quarrying Activity at Flattop Mesa. *Southwestern Lore* 49(4): 6-14.

Greiser, S. T. and P. D. Sheets
1979 Raw Material as a Functional Variable in Use-Wear Studies. In *Lithic Use Wear Studies*, edited by B. Hayden, pp. 289-299. Academic Press, New York.

Gumerman, George J. (editor)
1988 *The Anasazi in a Changing Environment.* Cambridge University Press, Cambridge.

Gurfinkel, D. and V. M. Franklin
1990 A Study of the Feasibility of Detecting Blood Residue on Artefacts. *Journal of Archaeological Science*, 15: 83-98.

Hardy, B. L.
1994 *Investigations of Stone Tool Function through Use-Wear, Residue and DNA Analyses at the Middle Paleolithic Site of La Quina, France.* Ph.D. Thesis, Indiana University.

Hardy, B. L. and G. T. Garufi
1998 Identification of Woodworking on Stone Tools Through Residue and

Use-wear Analyses: Experimental Results. *Journal of Archaeological Science*, 25: 177-184.
Haslam, Michael
2006 Potential Misidentification of In Situ Archaeological Tool-Residues: Starch and Conidia. *Journal of Archaeological Science*, 33: 114-121.
Haury, Emil W.
1950 *The Stratigraphy and Archaeology of Ventana Cave.* University of Arizona Press, Tuscon.
1956 The Lehner Mammoth Site. *The Kiva,* 21(3-4): 23-24.
1960 Association of Fossil Fauna and Artifacts at the Sulpher Springs Stage, Cochise Culture. *American Antiquity,* 25: 609-610.
1976 *The Hohokam, Desert Farmers and Craftsmen: Excavations at Snaketown, 1964-1965.* University of Arizona Press, Tucson.
Haward, F. N.
1912 The Chipping of Flint by Natural Agencies. *Prehistoric Society of East Anglia, Proceedings*, 1: 185-193.
1913 The Problem of the Eoliths. *Prehistoric Society of East Anglia, Proceedings*, 1: 347-359.
1921 The Fracture of Flint. *Prehistoric Society of East Anglia, Proceedings*, 3: 448-452.
Hayden, B. and W. Hutchings
1989 Whither the Billet Flake? In *Experiments in Lithic Technology*, edited by D. S. Amick and R. P. Mauldin, pp. 235-258, B.A.R. International Series, British Archaeological Reports, No. 528, Oxford, U.K.
Haynes, C. Vance Jr.
1993 Clovis-Folsom Geochronology and Climatic Change. In, *Kostenki to Clovis: Upper Paleolithic-Paleo-Indian Adaptations,* edited by Olga Soffer and N. D. Praslov, pp. 219-236. Plenum Press, New York.
Healy, James A.
1962 The Art of Knapping and Reproduction of Folsom Points. *Trowel and Screen*, 3(11): 3-11.
Heizer, R. F. and A. E. Treganza
1944 Mines and Quarries of the Indians of California. In, *Report XL of the State Mineralogist,* California Division of Mines, San Francisco.
Henry, Don O., C. Vance Haynes, and Bruce Bradley
1976 Quantitative Variation in Flaked Stone Debitage. *Plains Anthropologist*, 21: 57-61.
Hesse, Reinhard
1988 Origin of Chert: Diagenesis of Biogenic Siliceous Sediments. *Geoscience Canada*, 15: 171-192.
1989 Silica Diagenesis: Origin of Inorganic and Replacement Cherts. *Earth-Science Reviews*, 26: 253-284.
Hester, James J.
1972 *Blackwater Locality No. 1: A Stratified, Early Man Site in Eastern New Mexico.* Fort Burgwin Research Center, Southern Methodist University, Publication No. 8. Ranchos de Taos, New Mexico.

Hester, Thomas R. and Robert F. Heizer
1973 *Bibliography of Archaeology 1: Experiments, Lithic Technology, and Petrography.* Addison-Wesley Module in Anthropology 29.
Hibben, Frank C.
1941 Evidences of Early Occupation in Sandia Cave, New Mexico, and Other Sites in the Sandia-Manzano Region. *Smithsonian Institution Miscellaneous Collections,* 99(3): 1-44.
1946 The First Thirty-Eight Sandia Points. *American Antiquity,* 11: 257-258.
Hicks, Patricia A.
1994 Dating the Undiagnostic Lithic Scatter Through the Use of Patterned Changes in Debitage Attributes. In, *Archaic Hunter-Gatherer Archaeology in the American Southwest,* edited by Bradley J. Vierra. Contributions in Anthropology, 13(1), pp. 478-526. Eastern New Mexico University, Portales.
Higgins, H. C.
1984 Lithic Material Sources of the Ancho Canyon Area, York Canyon Region [New Mexico]. In *Philmont Conference on the Archaeology of North eastern New Mexico*, edited by C. J. Condie, pp. 137-150. New Mexico Archaeological Council, Albuquerque.
Hill, James N.
1970 *Broken K Pueblo: Prehistoric Social Organization in the American Southwest.* Anthropological Papers 18. University of Arizona, Tucson.
Hillsman, M. J.
1992 *Evaluation of Visible and Ultraviolet-Excited Attributes of Some Texas and Macroscopically Similar New Mexico Cherts.* Unpublished MA Thesis, Eastern New Mexico University. Portales, New Mexico.
Hoard, Robert J., Steven R. Holen, M. D. Glascock, H. Neff and J. Michael Elam
1991 Neutron Activation Analysis of Stone from the Chadron Formation and a Clovis Site on the Great Plains. *Journal of Archaeological Science* 19: 655-665.
Hoffman, C. Marshall
1985 Projectile Point Maintenance and Typology: Assessment with Factor Analysis and Canonical Correlation. In *For Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique, and Theory,* edited by Christopher Carr, pp. 566-612. Westport Publishers, Inc.
Holmes, W. H.
1890a A Quarry Workshop of the Flaked-stone Implement Makers in the District of Columbia. *American Anthropologist* 3: 1-26.
1890b Excavations in an Ancient Soapstone Quarry in the District of Columbia. *American Anthropologist* 3: 321-30.
1891 Aboriginal Novaculite Quarries in Garland County, Arkansas. *American Anthropologist,* Vol. 4, pp. 313-16.
1892a Modern Quarry Refuse and the Paleolithic Theory. *Science*, 20: 295-297.
1892c Aboriginal Quarries of Flakable Stone and Their Bearing Upon the

Question of Palaeolithic Man. *Proceedings of the American Association for the Advancement of Science*, 41: 279-280.

1893a Gravel Man and Palaeolithic Culture: A Preliminary Word. *Science*, 21: 29-30.

1894a Natural History of Flaked Stone Implements. In *Memoirs of the International Congress of Anthropology*, edited by C. Staniland Wake, pp.120-139. The Schultze Publishing Company, Chicago, Illinois.

1894b *An Ancient Quarry in Indian Territory.* Smithsonian Institution, Bureau of Ethnology, Washington, D. C.

1900 The Obsidian Mines of Hidalgo, Mexico. *American Anthropologist* n.s., 3: 405-16.

1907 Mines and Quarries. In, *Handbook of American Indians North of Mexico,* Bulletin 30, pp. 864-867. Bureau of Ethnology, Smithsonian Institution, Washington, D. C.

1919 Acquirement of Minerals-Quarrying and Mining. In, *Handbook of Aboriginal American Antiquities, Part 1: The Lithic Industries,* Bulletin 60. Bureau of Ethnology, Smithsonian Institution, Washington, D. C.

Honea, Kenneth H.

1965a The Bipolar Flaking Technique in Texas and New Mexico. *Texas Archaeological Society Bulletin*, 36: 259-267.

1965b A Morphology of Scrapers and Their Methods of Production. *Southwestern Lore,* 31: 25-40.

Huckell, Bruce B.

1988 Late Archaic Archaeology of the Tucson Basin: A Status Report. In *Recent Research on Tucson Basin Prehistory: Proceedings of the Second Tucson Basin Conference*, edited by William H. Doelle and Paul R. Fish, pp. 57-80 Institute for American Research Anthropological Papers No. 10, Tucson.

1996 Middle to Late Holocene Stream Behavior and the Transition to Agriculture in Southeastern Arizona. In *Early Formative Adaptations in the Southern Southwest*, edited by Barbara J. Roth, pp. 27-36. Monographs in World Archaeology No. 25. Prehistory Press, Madison, Wisconsin.

1998a An Analysis of the Flaked Stone Artifacts. In *Early Farmers of the Sonoran Desert: Archaeological Investigations at The Houghton Road Site, Tucson, Arizona*, edited by Richard Ciolek-Torello, pp. 89-117. Technical Series 72, Statistical Research Inc., Tucson, Arizona.

Huckell, Bruce B. and Lisa W. Huckell

1984 *Archaeological Investigations at the Milagro Site, A Late Archaic Site in the Eastern Tucson Basin.* MS on file, Arizona State Museum, University of Arizona, Tucson.

Hughes, Richard E.

1994 Intrasource Chemical Variability of Artefact-Quality Obsidians from the Casa Diablo Area, California. *Journal of Archaeological Science* 21: 263-271.

Hunt, E.D.
1992 Upgrading Site-catchment Analyses with the Use of GIS: Investigating the Settlement Patterns of Horticulturists. *World Archaeology* 24: 283-309.

Hyland, D. C., J. M. Tersak, J. M. Adovasio, and M. I. Segal
1990 Identification of the Species of Origin of Residual Blood on Lithic Material. *American Antiquity*, 55: 104-112.

Ingham, K. W. and Z. Dunikowska-Koniuszy
1965 The Distribution, Character and Basic Properties of Cherts of Southwestern Ontario. *Department Of Highways, Ontario, Report* No. RB106.

Irwin-Williams, Cynthia
1967 Picosa: The Elementary Southwestern Culture. *American Antiquity,* 32: 441-456.
1968 The Reconstruction of Archaic Culture History in the Southwestern United States. In *Archaic Prehistory in the Western United States: Symposium of the Society for American Archaeology Santa Fe, 1968*, edited by C. Irwin-Williams, pp. 19-23. Eastern New Mexico University Contributions in Anthropology Vol. 1, No. 3, Eastern New Mexico University Paleo-Indian Institute.
1973 *The Oshara Tradition: Origins of Anasazi Culture.* Contributions in Anthropology 5(1). Eastern New Mexico University, Portales.
1979 Post-Pleistocene Archaeology, 7000-2000 B.C. In, *Southwest,* edited by Alfonso A. Ortiz, Handbook of North American Indians, Vol. 9, pp. 31-42. Smithsonian Institution, Washington, D.C.
1980a Investigations at Salmon Ruin: Methodology and Overview. In, *Investigations at the Salmon Site: The Structure of Chacoan Society in the Northern Southwest,* edited by Cynthia Irwin-Williams and Phillip H. Shelley, pp. 135-211. Eastern New Mexico University, Portales.
1994 The Archaic of the Southwestern United States: Changing Goals and Research Strategies in the Last Twenty Five Years, 1964-1989. In, *Archaic Hunter- Gatherer Archaeology in the American Southwest,* edited by Bradley J. Vierra. Contributions in Anthropology, 13(1), pp. 478-526. Eastern New Mexico University, Portales.

Ives, D. J.
1983 Chert Sources and Identification in Archaeology: Can a Silk Purse be Made from a Sow's Ear? In *Lithic Resource Procurement: Proceedings from the Second Conference on Prehistoric Chert Exploitation*, edited by S. C. Vehik, pp. 211-224. Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Jacobsen, LouAnn
n.d. *A Source Analysis of Lithic Debris: Procurement and Exchange in the San Juan Basin.* Unpublished MA thesis, Department of Anthropology, University of New Mexico, Albuquerque.

Jahren, A. H., N. Toth, K. Schick, J. D. Clark, and R. G. Amundson
1997 Determining Stone Tool Use: Chemical and Morphological Analyses

of Residues on Experimentally Manufactured Stone Tools. *Journal of Archaeological Science*, 24: 245-250.

Janusas, Scarlett E.

1984 A Petrological Analysis of Kettle Point Chert and its Spatial and Temporal Distribution in Regional Prehistory. *National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper No. 128,* Ottawa.

Jeancon, J. A.

1923 *Excavations in the Chama Valley, New Mexico.* Bulletin 81, Bureau of American Ethnology. Washington.

Jelinek, Arthur J.

1967 *A Prehistoric Sequence in the Middle Pecos Valley, New Mexico.* Anthropological Papers No. 31, Museum of Anthropology, University of Michigan, Ann Arbor.

1976 Form, Function, and Style in Lithic Analysis. In, *Cultural Change and Continuity: Essays in Honor of James Bennett Griffith,* edited by C. Cleland, pp. 19-33, Academic Press, New York.

Johnson, K. L.

1987 *Contact Mechanics.* Cambridge University Press, Cambridge.

Johnson, L. Lewis

1978 A History of Flint-Knapping Experimentation, 1838-1976. *Current Anthropology*, 19(2): 337-372.

Judge, W. James

1970 Systems Analysis and the Folsom-Midland Question. *Southwestern Journal of Anthropology,* 26(1): 40-51.

1973 *The Paleo-Indian Occupation of the Central Rio Grande Valley, New Mexico.* University of New Mexico Press, Albuquerque.

Jury, Wilfred W.

1949 *Report on the Prehistoric Flint Workshops at Port Franks, Ontario.* Museum of Indian Archaeology Bulletin No. 8, University of Western Ontario. London, Ontario.

Kamminga, J.

1979 The Nature of Use Polish and Abrasive Smoothing on Stone Tools. In *Lithic Use-Wear Analysis,* edited by B. Hayden, pp. 143-157, Studies in Archaeology Series, New York: Academic Press.

Kamp, Kathryn A. and John C. Whittaker

1999 *Surviving Adversity: The Sinagua of Lizard Man Village.* University of Utah Anthropological Papers, No. 120. University of Utah Press, Salt Lake City.

Karlin, C. and M. Julien

1994 Prehistoric technology: A cognitive science? In *The Ancient Mind: Elements of Cognitive Archaeology,* edited by Colin Renfrew and Ezra B. W. Zubrow. New Directions in Archaeology Series, pp. 152-164. Cambridge University Press, Cambridge.

Kay, Marvin

1977 Wear Analysis and Unifacial Scraping Tool Morphology: Implications

For Studying Individual Use. In, *The Individual in Prehistory: Studies of Variability in Style in Prehistoric Technologies,* edited by James N. Hill and Joel Gunn, pp. 231-245, New York, Academic Press, New York.

1996 Microwear Analysis of Some Clovis and Experimental Chipped Stone Tools. In *Stone Tools: Theoretical Insights into Human Prehistory*, edited by G. H. Odell, pp. 315-344, Plenum Press, New York.

Kay, Marvin and R. Solecki

1999 Pilot Study of Burin Use-Wear from Shanidar Cave, Iraq. *Lithic Technology*, 25: 30-41.

Keeley, Lawrence H.

1980 *Experimental Determination of Stone Tool Uses: A Microwear Analysis.* The University of Chicago Press, Chicago.

Keeley, Lawrence H. and M. H. Newcomer

1977 Microwear Analysis of Experimental Flint Tools: A Test Case. *Journal of Archaeological Science*, 4: 29-62.

Keller, C.

1966 The Development of Edge Damage Patterns on Stone Tools. *Man*, 1: 501-511.

Kelly, Isabel T.

1964 *Southern Paiute Ethnography.* University of Utah Anthropological Papers 69. Salt Lake City, Utah.

Kidder, Alfred Vincent

1924 *An Introduction to the Study of Southwestern Archaeology, with a Preliminary Account of the Excavations at Pecos.* Papers of the Southwest Expedition 1. (Reprinted in 1962 by Yale University Press, New Haven.)

1932 *The Artifacts of Pecos.* Yale University Press, New Haven.

1936b Speculations on New World Prehistory. In, *Essays in Anthropology Presented to A. L. Kroeber,* pp. 143-152. University of California Press, Berkeley.

1938 Arrow-Heads or Dart Points. *American Antiquity,* 4: 156-157.

Kimball, L. R., J. R. Kimball, and P. E. Allen

1995 Microwear Polishes as Viewed Through the Atomic Force Microscope. *Lithic Technology*, 20: 6-28.

King, Adam, James W. Hatch and Barry E, Scheetz

1997 The Chemical Composition of Jasper Artefacts from New England and the Middle Atlantic: Implications for the Prehistoric Exchange of "Pennsylvania Jasper". *Journal of Archaeological Science* 24: 793-812.

Knowles, Sir Francis H. S.

1944 *The Manufacture of a Flint Arrowhead by Quartzite Hammer-Stone.* Pitt-Rivers Museum, Oxford University, Occasional Papers on Technology 1.

1952 *Stone-Worker's Progress: A Study of Stone Implements in the Pitt-Rivers Museum.* Pitt-Rivers Museum, Oxford University, Occasional Papers on Technology 6.

Knutsson, K.
1988 *Patterns of Tool Use: Scanning Electron Microscopy of Experimental Quartz Tools*. Societas Archaeologica Upsaliensis, AUN 10. Uppsala, Sweden.

Kooyman, B., M. E. Newman, and H. Ceri
1992 Verifying Reliability of Blood Residue Analysis on Archaeological Tools. *Journal of Archaeological Science*, 19: 265-270.

Krieger, Alex D.
1944 The Typological Concept. *American Antiquity,* Vol. 9, pp. 271-288.

Kuhn, S. L.
1990 A Geometric Index of Reduction of Unifacial Stone Tools. *Journal of Archaeological Science*, 17: 583-593.

Kujit, I., W. C. Prentiss, and D. J. Pokotylo
1995 Bipolar Reduction: An Experimental Study of Debitage Variability. *Lithic Technology*, 20: 116-127.

Kvamme, K. L.
1997 Patterns and Models of Debitage Dispersal in Percussion Flaking. *Lithic Technology*, 22: 122-138.

Kvamme, K.L. & M.A. Jochim
1989 The Environmental Basis of Mesolithic Settlement. In *The Mesolithic in Europe: Papers Presented at the Third International Symposium*, edited by C. Bonsall, pp. 1-12. John Donald, Edinburgh.

Laferty, Don
2000 Image Analysis: Historical Perspective. In *Practical Guide to Image Analysis*, ASM International: The Materials Information Society, pp. 1-14. ASM International, Materials Park, Ohio.

Lake, M. W., P. E. Woodman and S. J. Mithen
1998 Tailoring GIS Software for Archaeological Applications: An Example Concerning Viewshed Analysis. *Journal of Archaeological Science*, 25: 27-38.

Lankester, Sir E. Ray
1912 The Investigation of Flint. *Nature*, 90: 331-333.

Lawrence, R. A.
1979 Experimental Evidence for the Significance of Attributes Used in Edge-Damage Analysis. In *Lithic Use-Wear* Analysis, edited by B. Hayden, pp. 113-121, Studies in Archaeology Series, New York: Academic Press.

Leakey, L. S.
1954 Working Stone, Bone and Wood. In *A history of technology*, Vol. 1. edited by C. Singer et al., pp. 128-143. Oxford: Clarendon Press.

Leblanc, Raymond
1991 Wedges, Pieces Esquillees, Bipolar Cores, and Other Things: An Alternative to Shott's View of Bipolar Industries. *North American Archaeologist,* Vol. 13, No. 1, pp. 1-14.

Lekson, S. H.
1990 *Mimbres Archaeology of the Upper Gila, New Mexico.* Anthropological Papers of the University of Arizona, No. 53. University of Arizona Press, Tucson, Arizona.
1997 Points, Knives and Drills of Chaco Canyon. In, *Ceramics, Lithics and Ornaments of Chaco Canyon,* Vol.2, edited by F. J. Mathien, pp. 659-700. Publications in Archaeology 18G, Chaco Canyon Studies. National Park Service, Santa Fe.

Lemmonier, Pierre
1986 The Study of Material Culture Today: Toward an Anthropology of Technical Systems. *Journal of Anthropological Archaeology,* 5: 147-186.

Leo, R. F. and E. S. Barghoorn
1976 Silicification of Wood. *Botanical Museum Leaflet* 25, Harvard University.

Leonard, R. D., F. E. Smiley and C. M. Cameron
1989 Changing Strategies of Anasazi Lithic Procurement on Black Mesa, Arizona. In *Quantifying Diversity in Archaeology*, edited by R. D. Leonard and G. T. Jones, pp. 100-108. Cambridge University Press, Cambridge.

Lerner, H. J.
n.d. *The Keffer Site (AkGv-14): A Distributional and Microwear Analysis of a Scraper Assemblage.* (Unpublished manuscript in possession of the author.)
2000 *From Static Types to Dynamic Variables: Re-assessing Chipped Stone Tool Documentation and Analysis in Ontario*. Unpublished Masters Thesis, Department of Anthropology, McGill University, Montreal, Quebec, Canada.

Leroi-Gourhan, Andre
1993 *Gesture and Speech.* The MIT Press, Cambridge, Massachusetts.

Levi-Sala, Irene
1986 Use Wear and Post-Depositional Modification: A Word of Caution. *Journal of Archaeological Science*, 13: 229-244.

Linford, Laurance
1974 *Arroyo Hondo 1973 Lithics Analysis: Typology and Component Comparisons.* Ms. School of American Research, Santa Fe, New Mexico.

Longacre, William A.
1968 Some Aspects of Prehistoric Society in East-Central Arizona. In *New Perspectives in Archaeology*, edited by Sally R. Binford and Lewis R. Binford, pp. 89-102. Aldine, Chicago.

Love, D. W.
1997 Petrographic Description and Sources of Chipped Stone Artifacts in Chaco Canyon. In, *Ceramics, Lithics and Ornaments of Chaco Canyon,* Vol.2, edited by F. J. Mathien, pp. 610-642. Publications in Archaeology

18G, Chaco Canyon Studies. National Park Service, Santa Fe.

Loy, T. H.
1983 Prehistoric Blood Residues: Detection of Tool Surfaces and Identification of Species of Origin. *Science*, 220: 1269-1271.

Loy, T. H. and B. L. Hardy
1992 Blood Residue Analysis of 90,000 Year Old Stone Tools from Tabun Cave, Israel. *Antiquity*, 66: 24-35.

Luckert, Karl W.
1975 *The Navajo Hunter Tradition*. The University of Arizona Press. Tucson, Arizona.

MacCurdy, George Grant
1905 The Eolithic Problem: Evidence of a Rude Industry Antedating the Paleolithic. *American Anthropologist*, 7: 425-479.

MacNeish, Richard S.
1953 *Iroquois Pottery Types: A Technique for the Study of Iroquois Prehistory*. National Museum of Canada, Bulletin No. 124. Ottawa

MacNeish, Richard S., Geoffrey Cunnar, Gary Jessop, and Peggy Wilner
1994 *A Summary of the Paleo-Indian Discoveries in Pendejo Cave near Orogrande, New Mexico*. Annual Report for 1993, Andover Foundation for Archaeological Research, Andover.

Magne, Martin
1985 *Lithics and Livelihood: Stone Tool Technologies of Central and Southern Interior British Columbia*. National Museum of Man Mercury Series, Archaeological Survey of Canada, Paper No. 133. Ottawa.

Magne, Martin and David Pokotylo
1981 A Pilot Study in Bifacial Lithic Reduction Sequences. *Lithic Technology*, 10: 34-47.

Mansur-Franchomme, M. E.
1983 Scanning Electron Microscopy of Dry Hide Working Tools: the Role of Abrasives and Humidity in Microwear Polish Formation. *Journal of Archaeological Science*, 10: 223-230.

Marks, Anthony E. and Kathryn Monigal
1995 Modeling the Production of Elongated Blanks from the Early Levantine Mousterian at Rosh Ein Mor. In *The Definition and Interpretation of Levallois Technology*, edited by Harold L. Dibble and Ofer Bar-Yosef. Monographs in World Archaeology, No. 23, pp. 267-277. Prehistory Press Madison, Wisconsin.

Martin, Paul Sidney
1973 The Desert Culture: A Hunting and Gathering Adaptation. In, *The Archaeology of Arizona, A Study of the Southwest Region,* by P. S. Martin and F. Plog, pp. 69-80. Doubleday/Natural History Press, Garden City.

Matson, Richard G.
1991 *The Origins of Southwestern Agriculture*. University of Arizona Press, Tucson.

Mauldin, R. P. and D. S. Amick
1989 Investigating Patterning in Debitage from Experimental Bifacial Core Reduction. In *Experiments in Lithic Technology*, edited by D. S. Amick and R.P.Mauldin, pp. 67-88, B.A.R. International Series, British Archaeological Reports, No. 528, Oxford, U.K.

McAnany, Patricia A.
1988 The Effects of Lithic Procurement Strategies on Tool Curation and Recycling. *Lithic Technology* 17: 3-11.

McBrearty, Sally, Laura Bishop, Thomas Plummer, Robert Dewar, and Nicholas Conrad
1998 Tools Underfoot: Human Trampling as an Agent of Lithic Artifact Edge Modification. *American Antiquity*, 63(1): 108-129.

McCann, F. T.
1940 A New Source for Agate Artifacts in Central New Mexico. *Science*, 92: 259.

McDevitt, K. B.
1994 Results of Replicative Hide-Working Experiments: The Roles of Raw Material, Hide Condition, and Use-Wear Patterns in the Determination of Rhyolite Endscraper Function. *Lithic Technology*, 19: 93-97.

McKern, W. C.
1939 Midwestern Taxonomic Method as an Aid to Archaeological Culture Study. *American Antiquity,* Vol. 4, No.4, pp. 301-313.

Meeks, N. D., G. de G. Sieveking, M. S. Tite, and J. Cook
1982 Gloss and Use-Wear Traces on Flint Sickles and Similar Phenomena. *Journal of Archaeological Science*, 9: 317-340.

Meltzer, David J.
1993 Is There a Clovis Adaptation? In, *Kostenki to Clovis: Upper Paleolithic-Paleo-Indian Adaptations,* edited by Olga Soffer and N. D. Praslov, pp. 293-310. Plenum Press, New York.
1995 Clocking the First Americans. *Annual Review of Anthropology,* 24: 21-45.

Mewhinney, Hubert
1957 *A Manual for Neanderthals*. Austin: University of Texas Press.

Meyers, W. J.
1977 Chertification in the Mississippian Lake Valley Formation, Sacramento Mountains, New Mexico. *Sedimentology*, 24: 75-105.

Meyers, W. J. and A. T. James
1978 Stable Isotopes of Cherts and Carbonate Cements in the Lake Valley Formation (Mississippian), Sacramento Mts, New Mexico. *Sedimentology*, 25: 105-124.

Minichillo, Thomas J.
2005 *Middle Stone Age Lithic Study, South Africa: An Examination of Modern Human Origins*. PhD Dissertation, Department of Anthropology, University of Washington, Seattle.

Mitchell, Douglas R. and M. Steven Shackley
1995 Classic Period Hohokam Obsidian Studies in Southern Arizona. *Journal*

of Field Archaeology 22(3): 291-304.

Moir, J. Reid

1912 The Natural Fracture of Flint and its Bearing Upon Rudimentary Flint Implements. *Prehistoric Society of East Anglia, Proceedings*, 1: 171-84.

1914 The Large Non-Conchoidal Fracture Surfaces of Early Flint Implements. *Nature*, 94: 89.

1919 *Pre-Palaeolithic Man.* London: By the author.

Moore, Roger A.

1994 Archaic Projectile Point Typology/Chronology in Northern New Mexico and the Four Corners. In, *Archaic Hunter-Gatherer Archaeology in the American Southwest,* edited by Bradley J. Vierra. Contributions in Anthropology, 13(1), pp. 456-477. Eastern New Mexico University, Portales.

Morrow, J. E.

1997 End Scraper Morphology and Use-Life: An Approach for Studying Paleo-Indian Lithic Technology and Mobility. *Lithic Technology*, 22: 70-85.

Morrow, T. A.

1997 A Chip off the Old Block: Alternative Approaches to Debitage Analysis. *Lithic Technology*, 22: 51-69.

Muto, Guy R.

1971a A Stage Analysis of the Manufacture of Stone Tools. In, *Great Basin Anthropological Conference 1970: Selected Papers,* edited by C. Melvin Aikens, pp. 109-199. University of Oregon Anthropological Papers 1, Eugene, Oregon.

1971b *A Technological Analysis of the Early Stages in the Manufacture of Lithic Artifacts.* Unpublished MA Thesis, Idaho State University, Pocatello, Idaho.

Neill, W. T.

1952 The Manufacture of Fluted Points. *Florida Anthropologist*, 5: 9-16.

Nelson, Margaret C.

1984 Food Selection at Galaz: Inferences from Chipped Stone Analysis. In, *The Galaz Ruin: A Prehistoric Mimbres Village in Southeastern New Mexico,* by Roger Anyon and Steven A. LeBlanc, pp. 225-246. Maxwell Museum of Anthropology and the University of New Mexico Press, Albuquerque.

Neusius, Phillip D.

1988 Functional Analysis of Selected Flaked Lithic Assemblages from the Dolores River Valley: A Low-Power Microwear Approach. In, *Dolores Archaeological Program: Supporting Studies: Additive and Reductive Technologies,* compiled by Eric Blinman, Carl J. Phagan, and Richard H. Wilshusen, Chapter 5. United States Department of the Interior, Bureau of Reclamation, Engineering and Research Center. Denver, Colorado.

Newcomer, Mark H.

1971 Some Quantitative Experiments in Hand-Axe Manufacture. *World*

Archaeology, 3: 85-93.
1975 'Punch Technique' and Upper Paleolithic Blades. In *Lithic Technology*, edited by Earl H. Swanson, Jr., pp. 97-102, The Hague: Mouton.

Newcomer, Mark H. and L. H. Keeley
1979 Testing a Method of Microwear Analysis with Experimental Flint Tools. In *Lithic Use-Wear Analysis*, edited by B. Hayden, pp. 195-206, Studies in Archaeology Series, New York: Academic Press.

Newcomer, Mark H., R. Grace, and R. Unger-Hamilton
1986 Investigating Microwear Polishes with Blind Tests. *Journal of Archaeological Science*, 13: 203-217.
1987 Microwear Polishes, Blind Tests and Texture Analysis. In *The Human Uses of Flint and Chert: Papers from the Fourth International Flint Symposium*, edited by G. Sieveking and M. H. Newcomer, pp. 253-263, Cambridge: University of Cambridge Press.

Newman, J. R.
1994 The Effects of Distance on Lithic Material Reduction Technology. *Journal of Field Archaeology* 21(4): 491-501.

Newman, M. E. and P. Julig
1989 Protein Residues on Lithic Artifacts from a Stratified Boreal Forest Site. *Canadian Journal of Archaeology*, 13: 119-132.

Neilson, Axel E.
1991 Trampling the Archaeological Record: An Experimental Study. *American Antiquity*, 56: 483-503.

Nigro, Joseph D., Peter S. Ungar, Darryl J. de Ruiter and Lee R. Burger
2003 Developing a Geographic Information System (GIS) for Mapping and Analysing Fossil Deposits at Swartkrans, Gauteng Province, South Africa. *Journal of Archaeological Science*, 30: 317-324.

Nilsson, Sven
1868 *The Primitive Inhabitants of Scandinavia*. Edited by John Lubbock. London: Longmans, Green (first published in 1838-1843).

O'Brien, Michael J. and R. Lee Lyman
2003 *Cladistics in Archaeology*. University of Utah Press, Salt Lake City.

Odell, G. H.
1979 A New Improved System for the Retrieval of Functional Information from Microscopic Observation of Chipped Stone Tools. In *Lithic Use-Wear Analysis*, edited by B. Hayden, pp. 239-244. New York: Academic Press.
1981a The Mechanics of Use-Breakage of Stone Tools: Some Testable Hypotheses. *Journal of Field Archaeology*, 8: 197-209.
1975 Experiments in Lithic Reduction. In *Experiments in Lithic Technology*, edited by D. S. Amick and R. P. Mauldin, pp. 163-198, B.A.R. International Series, British Archaeological Reports, No. 528, Oxford, U.K.
1990 Brer Rabbit Seeks True Knowledge. In *The Interpretive Possibilities of*

Microwear Studies, edited by B. Graslund, H. Knutsson, K. Knutsson, and J. Taffinder, pp. 125-134, Societas Archaeological Upsaliensis, AUN 14, Uppsala.

Odell, G. H. and F. Cowan

1988 Experiments with Spears and Arrows on Animal Targets. *Journal of Field Archaeology*, 13: 195-212.

Odell, G. H. and F. Odell-Vereecken

1980 Verifying the Reliability of Lithic Use-Wear Assessments by 'Blind Tests': The Low Power Approach. *Journal of Field Archaeology*, 7: 87-120.

O'Hara, James

1988 Projectile Point Analysis. In, *The Border Star 85 Survey: Toward an Archeology of Landscapes,* edited by T. J. Seaman, W. H. Doleman, and R. C. Chapman, pp. 191-208. Office of Contract Archeology, University of New Mexico, Albuquerque.

Ohnuma, K. and C. Bergman

1982 Experimental Studies in the Determination of Flaking Mode. *Bulletin of the Institute of Archaeology*, 19: 161-170.

Olivier, Laurent

1999 The Origins of French Archaeology. *Antiquity,* 73: 176-183.

Olszewski, Deborah I. and Alan H. Simmons

1982 Tools for Thought: Some Comments on the Analysis of Puebloan Chipped Stone Assemblages. *The Kiva*, 48(1-2): 109-115.

Ozbun, T. L.

1987 *A Technological Analysis of the Lithic Assemblage from the Buttonhole Rockshelter/Quarry Site, Northeast New Mexico.* Unpublished MA thesis, Washington State University, Pullman.

Painter, Floyd E.

1965 The Cattail Creek Fluting Tradition. *The Chesopiean*, 3(1): 11-18.

1966 Workshop Debris or Crude Tools? *The Chesopiean*, 5(1): 23-25.

1972 The Cattail Creek Fluting Tradition and its Complex-Determining Lithic Debris. *Bulletin of the Massachusetts Archaeological Society*, 34(1-2): 6-11.

Parkins, William G.

1977 *Onondaga Chert: Geological and Palynological Studies as Applied to Archaeology.* MSc Thesis, Brock University.

Parr, G. and W. Polzleitner

2001 Fundamentals. In *Digital Image Analysis: Selected Techniques and Applications*, edited by Walter G. Kropatsch and Horst Bischof, pp. 373-392. Springer, New York.

Parry, W. J.

1987a Sources of Chipped Stone Material. In, *Prehistoric Stone Technology on Northern Black Mesa, Arizona,* edited by W. J. Parry and A. L. Chistenson, pp. 21-42. Center for Archaeological Investigations, Southern

Illinois University, Carbondale.

1987b Technological Change: Temporal and Functional Variability in Chipped Stone Debitage. In, *Prehistoric Stone Technology on Northern Black Mesa, Arizona,* edited by W. J. Parry and A. L. Chistenson, pp. 199-256. Center for Archaeological Investigations, Southern Illinois University, Carbondale.

1994 Prismatic Blade Technologies in North America. In, *The Organization of American Prehistoric Chipped Stone Tool Technologies*, edited by Philip J. Carr, pp. 87-98. International Monographs in Prehistory, Archaeological Series, No.7, Ann Arbor, Michigan.

Parry, W. J. and A. L. Christenson

1987 *Prehistoric Stone Technology on Northern Black Mesa, Arizona.* Center for Archaeological Investigations Occasional Paper No. 12. Carbondale, Southern Illinois University.

Parry, W. J., F. E. Smiley, and Galen Burgett

1994 The Archaic Occupation of Black Mesa. In, *Archaic Hunter-Gatherer Archaeology in the American Southwest,* edited by Bradley J. Vierra. Contributions in Anthropology, 13(1), pp. 185-230. Eastern New Mexico University, Portales.

Parry, W. J. and John D. Speth

1984 *The Garnsey Spring Campsite: Late Prehistoric Occupation in South-eastern New Mexico.* Research Reports in Anthropology, Contribution No. 10, Museum of Anthropology, University of Michigan, Ann Arbor.

Patten, R.

1980 Soft Stonehammer Percussion. *Flintknapper's Exchange*, 3: 17.

Patterson, L. W.

1981 The Analysis of Striking Platform Geometry. *Flintknapper's Exchange*, 4: 18-20.

1982 The Importance of Flake Size Distributions. *Contract Abstracts and CRM Archaeology*, 3(1): 70-72.

Patterson, L. W. and J. B. Sollberger

1978 Replication and Classification of Small Size Lithic Debitage. *Plains Anthropologist*, 23(80): 103-112.

Pearson, Deborah M., Karol Chandler-Ezell and James A.Zeidler

2004 Maize in Ancient Ecuador: Results of Residue Analysis of Stone Tools from the Real Alto Site. *Journal of Archaeological Science*, 31: 423-442.

Pei, Wen Chung

1936 Le Rôle des Phénomènes Naturels dans l' Éclatement et le Façonnement des Roches Dures Utilisées par l'Homme Préhistorique. *Revue de Géographie Physique et de Géologie Dynamique*, 9: 349-423.

Pelcin, A

1997a The Effect of Indentor Type on Flake Attributes: Evidence From a Controlled Experiment. *Journal of Archaeological Science*, 24: 613-621.

1997b The Effect of Core Surface Morphology on Flake Attributes: Evidence From a Controlled Experiment. *Journal of Archaeological Science*, 24: 749-756.

1997c The Formation of Flakes: The Role of Platform Thickness and Exterior Platform Angle in the Production of Flake Initiations and Terminations. *Journal of Archaeological Science*, 24: 1107-1113.

1998 The Threshold Effect of Platform Width: A Reply to Davis and Shea. *Journal of Archaeological Science*, 25: 615-620.

Peterson, Jane, Douglas R. Mitchell and M. Steven Shackley

1997 The Social and Economic Contexts of Lithic Procurement: Obsidian from Classic-Period Hohokam Sites. *American Antiquity* 62(2): 231-259.

Phagan, Carl J.

1979 *Interpretative Suggestions for Flaked Lithic Debitage.* Ms. on file, Dolores Archaeological Program. Dolores, Colorado.

1980a *Interpretative Suggestions for Flaked Lithic Implements.* Ms. on file, Dolores Archaeological Program. Dolores, Colorado.

1980b *Recoding of Lithic Preliminary Sorting Variables.* Ms. on file, Dolores Archaeological Program. Dolores, Colorado.

1982a *Reductive Technology Laboratory 1979 Report.* Dolores Archaeological Program Technical Reports DAP-044. U.S. Bureau of Reclamation, Upper Colorado Region, Salt Lake City.

1983 *Reductive Technologies Group Midlevel Research Design.* Dolores Archaeological Program Technical Reports DAP-060. U.S. Bureau of Reclamation, Upper Colorado Region, Salt Lake City.

1986 Reductive Technologies. In, *Dolores Archaeological Program Final Synthetic Report,* compiled by David A. Breternitz, Christine K. Robinson, and G. Timothy Gross, Chapter 3. U.S. Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver.

1988a Projectile Point Analysis, Part I: Production of Statistical Types and Subtypes. In, *Dolores Archaeological Program Supporting Studies: Additive and Reductive Technologies,* compiled by Eric Blinman, Carl J. Phagan, and Richard H. Wilshusen, Chapter 2. U.S. Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver.

1988b Projectile Point Analysis, Part II: Comparison of Statistical and Intuitive Typologies. In, *Dolores Archaeological Program Supporting Studies: Additive and Reductive Technologies,* compiled by Eric Blinman, Carl J. Phagan, and Richard H. Wilshusen, Chapter 3. U.S. Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver.

1993 *The Stone Artifacts from Arroyo Hondo Pueblo.* Arroyo Hondo Archaeological Series, Vol. 8, Part II. School of American Research Press. Santa Fe, New Mexico

Phagan, Carl J. and Thomas H. Hruby
1984 *Dolores Archaeological Program Reductive Technologies Manual: Preliminary Analysis Systems and Procedures.* Dolores Archaeological Program Technical Reports DAP-150. U.S. Bureau of Reclamation, Upper Colorado Region, Salt Lake City.

Phagan, Carl J. and Edward R. Maloney
1980 *Plans for 1981 Lithic Raw Material Study.* Ms. on file, Dolores Archaeological Program, Dolores, Colorado.

Phillips, W. A.
1900 Aboriginal Quarries and Shops at Mill Creek, Illinois. *American Anthropologist* 2(1): 37-52.

Plisson, H. and M. Mauger
1992 Chemical and Mechanical Alteration of Micro-Wear Polishes: An Experimental Approach. *Helenium*, 28: 3-16.

Pomerantz, H.J.
1981 ACRONYM: A Geographic Information System for Archaeology. *Southwestern Lore* 47: 7-11.

Post, Stephen S.
2002 Emerging From the Shadows: The Archaic Period in the Northern Rio Grande. In *Traditions, Transitions, and Technologies: Themes in Southwestern Archaeology, Proceedings of the 2000 Southwest Symposium*, edited by Sarah H. Schlanger, pp. 33-48. University Press of Colorado, Boulder.

Poulton, Dana R.
1985 An Analysis of the Draper Site Chipped Lithic Artifacts. *Research Report No. 15, London Museum of Archaeology.* London, Ontario

Prentiss, W. C.
1998 The Reliability and Validity of a Lithic Debitage Typology: Implications for Archaeological Interpretation. *American Antiquity*, 63: 635-650.

Pryor, J. H.
1988 The Effects of Human Trample Damage on Lithics: A Model of Crucial Variables. *Lithic Technology*, 17: 45-50.

Pond, A. W.
1967 Primitive Methods of Working Stone, Based on Experiments of Havlor L. Skavlem. *Logan Museum, Beloit College Bulletin*, 2: 1.

Proudfoot, V. B.
1965 Bringing Archaeology to Life. *Advancement of Science*, July 1965: 125-133.
1966 Experiments in Archaeology. *Science Journal*, 3: 59-64.

Ramsden, Peter G.
1990 The Hurons: Archaeology and Culture History. In, *The Archaeology of Southern Ontario to A.D. 1650,* Occasional Publication of the London Chapter, OAS No. 5, edited by Chris J. Ellis and Neal Ferris, pp. 361-384.

Rapp, Jr., G. and Christopher L.Hill
1998 *Geoarchaeology: The Earth-Science Approach to Archaeological Interpretation.* Yale University Press, New Haven and London.
Ray, Jack H.
1981 *A Study of Chert Resources in the Truman Reservoir: Availability, Procurement, and Utilization.* Unpublished MA Thesis, Department of Anthropology, University of Missouri-Columbia.
1982 A Test for the Quality and Quantity of Chert Nodules in Stream-Deposited Chert Sources. *Lithic Technology* 11: 5-12.
Ricklis, Robert A. and Kim A. Cox
1993 Examining Lithic Technological Organization as a Dynamic Cultural Sub-System: The Advantages of an Explicitly Spatial Approach. *American Antiquity* 58(3): 444-461.
Roberts, Frank H. H. Jr.
1938 The Folsom Problem in American Archaeology. *Annual Report of the Smithsonian Institution,* pp. 531-546. U.S. Government Printing Office, Washington, D.C.
Ritchie, William A.
1961 A Typology and Nomenclature for New York Projectile Points. *New York State Museum and Science Service, Bulletin No. 384,* Albany, N.Y.
Rogers, M. J.
1958 San Dieguito Implements from the Terraces of the Rincon-Patano and Rillito Drainage System. *The Kiva,* 24(1): 1-23.
Ronan, Avraham
1995 The Levallois Method as Cultural Constraint. In *The Definition and Interpretation of Levallois Technology,* edited by Harold L. Dibble and Ofer Bar-Yosef. Monographs in World Archaeology, No.23, pp. 293-304. Prehistory Press, Madison, Wisconsin.
Roosa, William B.
1956a Preliminary Report on the Lucy Site. *El Palacio,* 63: 36-49.
1956b The Lucy Site in Central New Mexico. *American Antiquity,* 21: 310.
Ross, J. A.
1973 Macho Draw Chert Quarry Excavation, Chaves County, New Mexico. *Awanyu,* 1(4): 26-31.
Roth, Barbara J.
1996a Introduction: Early Hunters, Gatherers, and Farmers in the Southern Southwest. In *Early Formative Adaptations in the Southern Southwest.* Edited by Barbara J. Roth, pp. 1-4. Monographs in World Archaeology No. 25. Prehistory Press, Madison, Wisconsin.
1996b *Regional Land Use in the Late Archaic of the Tucson Basin: A View from the Upper Bajada. In* Early Formative Adaptations in the *Southern Southwest*, edited by Barbara J. Roth, pp. 37-48. Monographs in World Archaeology No. 25. Prehistory Press, Madison, Wisconsin.
Rottensteiner, F.
2001 Precise Photogrammetric Measurement. In *Digital Image Analysis:*

Selected Techniques and Applications, edited by Walter G. Kropatsch and Horst Bischof, pp. 411-438. Springer, New York.

Sayles, E. B.

1983 *The Cochise Cultural Sequence in Southwestern Arizona.* Anthropological Papers No. 42. University of Arizona, Tucson.

Schiffer, Michael B.

1977 *Behavioral Archaeology.* Academic Press, New York.

Schlanger, Nathan

1990 Technique as Human Action: Two Perspectives. *Archaeological Review from Cambridge,* 9: 18-26.

1994 Mindful technology: Unleashing the *chaine operatoire* for an archaeology of the mind. In *The Ancient Mind: Elements of Cognitive Archaeology,* edited by Colin Renfrew and Ezra B. W. Zubrow. New Directions in Archaeology Series, pp. 143-151. Cambridge University Press, Cambridge.

Schlanger, Sarah H. and Patrick L. Harden

1983 *1979 and 1980 Probability Survey of Cline Crest, Grass Mesa, Beaver Point, Trimble Point, and Hoppe Point Localities.* Dolores Archaeological Program Technical Reports DAP-118. U.S. Bureau of Reclamation, Upper Colorado Region, Salt Lake City.

Schleicher, Ch.

1927 Un Industrie Qui Disparait: La Taille des Silex Modernes. *L'Homme Préhistorique*, 14(5-6): 113-133.

Schutt, Jeanne A.

1980 An Invesigation of the Relationship between Flakes and Small Angular Debris: Attributes that may be used in the Identification of Archaic and Anasazi Lithic Assembalges. In, *Human Adaptation in a Marginal Environment: The UII Project,* edited by J. Moore and J. Winter, pp. 390-401. Office of Contract Archaeology, University of New Mexico, Albuquerque.

1988 Formal Lithic Tool Analysis. In, *The Border Star 85 Survey: Toward an Archeology of Landscapes,* edited by T. J. Seaman, W. H. Doleman, and R. C. Chapman, pp. 209-230. Office of Contract Archeology, University of New Mexico, Albuquerque.

1997a Excavation of FA2-13 (LA 33741). In *Archaeology of the Farmington Sector of the Elena Gallegos Project*, edited by Joseph A. Tainter, pp. 149-166, Heritage Resources Management Report No. 16, USDA Forest Service Southwestern Region.

1997b Lithic Analysis. In *Archaeology of the Farmington Sector of the Elena Gallegos Project*, edited by Joseph A. Tainter, pp. 167-228, Heritage Resources Management Report No. 16, USDA Forest Service Southwestern Region.

Schwartz, Alfred

1914 Some Suggestions for Organized Research on Flint Implements. *Prehistoric Society of East Anglia, Proceedings*, 1: 449-454.

Scott Cummings, Linda
1997a Pollen Analysis of FA2-13. In *Archaeology of the Farmington Sector of the Elena Gallegos Project*, edited by Joseph A. Tainter, pp. 323-326, Heritage Resources Management Report No. 16, USDA Forest Service Southwestern Region.

Sell, A. D.
1997 Chipped Stone Analysis at the Bluff Great House. In, *1996 Excavations at the Bluff Great House.* Ms. on file, Department of Anthropology, University of Colorado, Boulder and Abajo Archaeology, Bluff Utah.

Sellers, G. E.
1886 Observations on Stone-Chipping. *Smithsonian Institution Annual Report for 1885:* 871-891.

Sellet, Frederic
1995 Chaine Operatiore: The Concept and its Applications. *Lithic Technology*, 18: 106-112.

Semenov, S.A.
1964 *Prehistoric Technology.* Translated by M.W. Thompson. Cory, Adams and Mackay. London.

Shackley, M. S.
1988 Sources of Archaeological Obsidian in the Southwest: An Archaeological, Petrological, and Geochemical Study. *American Antiquity*, 53: 752-772.
1992 The Upper Gila River Gravels as an Archaeological Obsidian Source Region: Implications for Models of Exchange and Interaction. *Geoarchaeology* 7(4): 315-326.
1996 Range and Mobility in the Early Hunter-gatherer Southwest. In *Early Formative Adaptations in the Southern Southwest*, edited by Barbara J. Roth, pp. 5-16. Monographs in World Archaeology No. 25. Prehistory Press, Madison, Wisconsin.

Shanks, Orin C., Robson Bonnichsen, Anthony T. Vella and Walt Ream
2001 Recovery of Protein and DNA Trapped in Stone Tool Microcracks. *Journal of Archaeological Science*, 28: 965-972.

Shea, John J. and Joel D. Klenck
1993 An Experimental Investigation of the Effects of Trampling on the Results of Lithic Microwear Analysis. *Journal of Archaeological Science* 20:175-194.

Shelley, P. H.
1983 *Lithic Specialization at Salmon Ruin, San Juan County, New Mexico.* Unpublished Ph.D. Dissertation, Department of Anthropology, Washington State University, Pullman.

Shen, Chen
1999 Were "Utilized Flakes" Utilized? An Issue of Lithic Classification in Ontario Archaeology. *Ontario Archaeology*, 68: 63-73.

Shott, M. J.
1989 Tool-Class Use Lives and the Formation of Archaeological Assemblages. *American Antiquity,* Vol. 54, No. 1, pp. 9-30.

1995a How Much is a Scraper? Curation, Use Rates, and the Formation of a Scraper Assemblage. *Lithic Technology*, 20: 53-72.

1996 An Exegesis of the Curation Concept. *Journal of Anthropological Research*, 52: 259-280.

2002 Weibull Estimation of Use-Life Distribution in Experimental Spear-Point Data. *Lithic Technology*, 27: 93-109.

Shott, M. J., A. P. Bradbury, P. J. Carr, and G. H. Odell

2000 Flake Size from Platform Attributes: Predictive and Empirical Approaches. *Journal of Archaeological Science*, 27: 877-894.

Shott, Michael and Paul Sillitoe

2001 The Mortality of Things: Correlates of Use-Life in Wola Material Culture
Using Age-at-Census Data. *Journal of Archaeological Method and Theory*, 8: 269-302.

2004 Modeling Use-Life Distributions in Archaeology Using New Guinea Wola Ethnographic Data. *American Antiquity*, 69: 336-352.

Simms, Steven R.

1989 Conceptualizing the Paleoindian and Archaic in the Great Basin. In *Early Human Occupation in Far Western North America: The Clovis-Archaic Interface*, edited by Judith A. Willig, C. Melvin Aikens, and John L. Fagan, pp. 41-52. Nevada State Museum Anthropological Papers, Vol. 21, Carson City, Nevada.

Smith, Anne M.

1974 *Ethnography of the Northern Utes*. University of New Mexico Papers in Anthropology 17. Albuquerque, New Mexico.

Smith, P. R. and M. T. Wilson

1992 Blood Residues on Ancient Tool Surfaces: A Cautionary Note. *Journal of Archaeological Science*, 19: 237-241.

Smolla, G.

1987 Prehistoric Flint Mining: The History of Research-a Review. In, *The Human Uses of Flint and Chert: Proceedings of the 4th International Flint Symposium,* edited by G. de G. Sieveking and M. H. Newcomer, pp. 127-129. Cambridge University Press, Cambridge.

Sollberger, J. B.

1880 The Basic Tool Kit Required to Make and Notch Arrowshafts for Stone Points. *Texas Archaeological Society Bulletin*, 40: 232-240.

1970 Preforms Are Not Projectile Point Types. *Oklahoma Anthropological Society Bulletin*, 19: 151-154.

1971 A Technological Study of Beveled Knives. *Plains Anthropologist*, 16: 209-218.

1976 Bifacing Patterns on Prismatic Blades. *Texas Archaeological Society Bulletin*, 47: 261-267.

Speth, John D.

1972 Mechanical Basis of Percussion Flaking. *American Antiquity*, 37: 34-60.

1974 Experimental Investigation of Hard-Hammer Percussion Flaking. *Tebiwa*, 17(1): 7-36.

1975 Miscellaneous Studies in Hard-Hammer Percussion Flaking: The Effects of Oblique Impact. *American Antiquity*, 20: 203-207.

1981 The Role of Platform Angle and Core Size in Hard-Hammer Percussion Flaking. *Lithic Technology*, 10: 16-21.

Spikins, P., C. Conneller, H. Ayestaran and B. Scaife

2001 GIS Based Interpolation Applied to Distinguishing Occupation Phases of Early Prehistoric Sites. *Journal of Archaeological Science*, 29: 1235-1245.

Stahle, David W. and James E. Dunn

1982 An Analysis and Application of the Size Distribution of Waste Flakes From the Manufacture of Bifacial Stone Tools. *World Archaeology*, 14(1): 84-97.

1984 *An Experimental Analysis of the Size Distribution of Waste Flakes from Biface Reduction*. Technical Paper No. 2. Arkansas Archaeological Survey, Fayetteville.

Stein, C. L.

1982 Silica Recrystallization in Petrified Wood. *Journal of Sedimentary Petrology*, 52: 1277-1282.

Stemp, W. J. and M. Stemp

2001 UBM Laser Profilometry and Lithic Use-Wear Analysis: A Variable Length Scale Investigation of Surface Topography. *Journal of Archaeological Science*, 28: 81-88.

2003 Documenting Stages of Polish Development on Experimental Stone Tools: Surface Characterization by Fractal Geometry Using UBM Laser Profilometry. *Journal of Archaeological Science*, 30: 287-296.

Steward, Julian H.

1938 Basin-Plateau Aboriginal Sociopolitical Groups. *Bureau of American Ethnology Bulletin* 120.

Stone, Tammy

1998 *The Prehistory of Colorado and Adjacent Areas*. University of Utah Press, Salt Lake City, Utah.

Straus, L. G.

1978a Thoughts on Solutrean Concave Base Point Distribution. *Lithic Technology* 6: 32-5.

1978b Of Neanderthal Hillbillies, Origin Myths and Stone Tools: Notes on Upper Paleolithic Assemblage Variability. *Lithic Technology* 7: 36-9.

1980 The Role of Raw Materials in Lithic Assemblage Variability. *Lithic Technology* 9(3): 68-72.

Taylor, W.

1898 The Pueblos and Ancient Mines near Allison, New Mexico. *American Antiquarian* 20(4): 258-261.

Titmus, G. L. and J. C. Woods

1986 An Experimental Study of Projectile Point Fracture Patterns. *Journal of California and Great Basin Anthropology*, 8(1): 33-49

Tixier, J.

1974 *Glossary for the Description of Stone Tools, with Special Reference to the Epi-Paleolithic of the Maghreb.* Translated by M. H. Newcomer. Newsletter of Lithic Technology Special Publication, No. 1.

Toll, Mollie S.

1997a Food and Fuel Use at FA2-13. In *Archaeology of the Farmington Sector of the Elena Gallegos Project*, edited by Joseph A. Tainter, pp. 289-296, Heritage Resources Management Report No. 16, USDA Forest Service Southwestern Region.

Tomka, S. A.

1990 Differentiating Lithic Reduction Techniques: An Experimental Approach.
In *Experiments in Lithic Technology*, edited by D. S. Amick and R. P. Mauldin, pp. 137-162, B.A.R. International Series, British Archaeological Reports, No. 528, Oxford, U.K.

Torrence, R.

1984 *Production and Exchange of Stone Tools.* Cambridge University Press, Cambridge.

Trigger, B. G.

1989 *A History of Archaeological Thought.* Cambridge: Cambridge University
Press.

Tringham, Ruth, Glenn Cooper, George Odell, Barbara Voytek, and Anne Whitman

1974 Experimentation in the Formation of Edge Damage: A New Approach to Lithic Analysis. *Journal of Field Archaeology*, 1:171-195.

Truncer, James J.

1990 Perkiomen Points: A Study in Variability. In *Experiments and Observations on the Terminal Archaic of the Middle Atlantic Region.* edited by Roger W. Moeller, pp. 1-62, Bethlehem, CT: Archaeological Services.

Tuross, N., I. Barnes, and R. Potts

1994 Protein Identification of Blood Residues on Experimental Stone Tools. *Journal of Archaeological Science*, 23: 289-296.

Underhill, Ruth M.

1967 *The Navajos*. University of Oklahoma Press. Norman, Oklahoma.

Unger-Hamilton, R.

1984 The Formation of Use-Wear Polish on Flint: Beyond the "Deposit Versus Abrasion" Theory. *Journal of Archaeological Science*, 11: 91-98.

Vaughan, P. C.

1981b *Lithic Microwear Experimentation and the Functional Analysis of a Lower Magdalenian Stone Tool Assemblage*. Ph.D. Dissertation, Department of Anthropology, University of Pennsylvania, Philadelphia.

1985 *Use-wear Analysis of Flaked Stone Tools.* The University of Arizona Press, Tucson, Arizona.

Vehik, S. C.
1986 The Effects of Trade on Resource Procurement Behavior: A Late Prehistoric Example from the Southern Plains. *Plains Anthropologist* 31(114 Part 2): 141-154.

Vierra, Bradley J.
1994b Introduction. In, *Archaic Hunter-Gatherer Archaeology in the American Southwest,* edited by Bradley J. Vierra. Contributions in Anthropology, 13(1), pp. 5-61. Eastern New Mexico University, Portales.
1994c Archaic Hunter-Gatherer Mobility Strategies in Northwestern New Mexico. In, *Archaic Hunter-Gatherer Archaeology in the American Southwest,* edited by Bradley J. Vierra. Contributions in Anthropology, 13(1), pp. 121-154. Eastern New Mexico University, Portales.

Warren, A. H.
1967 Description of Rock Specimens. In, *An Archaeological Survey of the Chuska Valley and the Chaco Plateau, New Mexico,* edited by A. H. Harris, J. Shoenwetter and A. H. Warren, pp. 110-134. Musuem of New Mexico Press, Santa Fe.
1974 The Ancient Mineral Industries of Cerro Perdenal, Rio Arriba County, New Mexico. In, *Guidebook, 25th Field Conference: Ghost Ranch,* pp. 87-90. New Mexico Geological Society, Albuquerque.
1979 Prehistoric Mineral Resources of the Gallo Wash District. In, *Cultural Resources of the Alamito Coal Lease Area, Northwestern New Mexico,* edited by J. P. Wilson, pp. 14-25. Alamito Coal Company, Tuscon.
1984 Prehistoric Mineral Resources of the Lower Rio Puerco. In, *Inventory Survey of the Lower Hidden Mountain Flood-pool. Lower Rio Puerco Drainage, Central New Mexico,* edited by P. L. Eidenbach, pp. 67-75. Human Systems Research, Inc., Tularosa.
1988 Notes on the Geology and Mineral Resources of the Jarilla Mountains Area, Otero County, New Mexico. In, *The Border Star 85 Survey: Toward an Archeology of Landscapes,* edited by T. J. Seaman, W. H. Doleman, and R. C. Chapman, pp. 273-279. Office of Contract Archeology, University of New Mexico, Albuquerque.

Warren, A. H. and Roger Moore
1996 *Lithic Identification Codes*. Adaptation of Helen Warren's Lithic Material Type Codes. Aztec, New Mexico.

Warren, Claude N. and Carl J. Phagan.
1988 Fluted Points in the Mojave Desert: Their Technology and Cultural Context. In *Early Human Occupation in Far Western North America: The Clovis-Archaic Interface*, edited by Judith A. Willig, C. Melvin Aikens and John L. Fagan, pp. 41-52. Nevada State Museum Anthropological Papers, Vol. 21, Carson City, Nevada.

Warren, S. Hazzledine
1905 On the Origin of Eolithic Flints by Natural Causes, Especially by the Foundering of Drifts. *Journal of the Royal Anthropological Institute*, 35: 337-364.

1913 The Problems of Flint Fracture. *Man*, 13:37.
1914 The Experimental Investigation of Flint Fracture and its Application to Problems of Human Implements. *Journal of the Royal Anthropological Institute*, 44: 412-450.
1924 The Flint Flakings of the Waybourne Crag. *Geological Magazine*, 41: 309-311.

Watson, William
1950 *Flint Implements*. London: Trustees of the British Museum.

Watson, Patty Jo, Steven A. Le Blanc, and Charles L. Redman
1971 *Explanation in Archaeology*. New York: Columbia University Press.

White, Anita M., Lewis R. Binford and Mark L. Papworth
1963 Miscellaneous Studies in Typology and Classification. *Museum of Anthropology, The University of Michigan, Anthropological Papers,* No. 19, Ann Arbor.

Whittaker, John C.
1984 *Arrowheads and Artisans: Stone Tool Manufacture and Individual Variation at Grasshopper Pueblo.* Ph.D. dissertation, University of Arizona. Ann Arbor: University Microfilms.
1987a Individual Variation as an Approach to Economic Organization: Projectile Points at Grasshopper Pueblo, Arizona. *Journal of Archaeological Science,* 14(4): 465-479.
1987b Making Arrowpoints in a Prehistoric Pueblo. *Lithic Technology,* 16(1): 1-12.

Whittlesey, Stephanie, and Richard Ciolek-Torello
1996 The Archaic-Formative Transition in the Tucson Basin. In *Early Formative Adaptations in the Southern Southwest*, edited by Barbara J. Roth, pp. 49-64. Monographs in World Archaeology No. 25. Prehistory Press, Madison, Wisconsin.

Wiant, M. D. and H. Hassen
1983 Deposited Chert Sources: A Closer Look at Lithic Availability and Human Procurement. *Lithic Technology* 12(2): 43-45.
1985 The Role of Lithic Resource Availability and Accessibility in the Organization of Technology. In, *Lithic Resource Procurement: Proceedings from the Second Conference on Prehistoric Chert Exploitation,* edited by S. C. Vehik, pp. 101-114. Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Wilke, P. J. and A. B. Schroth
1989 Lithic Raw Material Prospects in the Mohave Desert, California. *Journal of California and Great Basin Anthropology* 11(2): 146-174.

Willig, Judith A. and C. Melvin Aikens
1988 The Clovis-Archaic Interface in Far Western North America. In *Early Human Occupation in Far Western North America: The Clovis-Archaic Interface*, edited by Judith A. Willig, C. Melvin Aikens, and John L. Fagan, pp. 1-41. Nevada State Museum Anthropological Papers, Vol. 21, Carson City, Nevada.

Wills, W. H. III
1988a *Early Prehistoric Agriculture in the American Southwest.* School of American Research Press, Santa Fe, New Mexico.
1988b Early Agriculture and Sedentism in the American Southwest: Evidence and Interpretations. *Journal of World Prehistory*, 2: 445-488.
Wills, W. H. III and Bruce B. Huckle
1994 Economic Implications of Changing Land-Use Patterns in the Late Archaic. In *Themes in Southwest Prehistory*, edited by George J. Gumerman, pp. 33-52. School of American Research Press, Santa Fe, New Mexico.
Wilmsen, Edwin N.
1965 An Outline of Early Man Studies in the United States. *American Antiquity,* 31: 172-192.
1970 Lithic Analysis and Cultural Inference: A Paleo-Indian Case. *Anthropological Papers of the University of Arizona,* No. 16, The University of Arizona Press, Tucson, Arizona.
Wilson, John P.
1979 *Cultural Resources of the Alamito Coal Lease Area, Northwestern New Mexico.* Alamito Coal Co. Tuscon, Arizona.
Wilson, Thomas
1891 Mines and Workshops of Flint: Report of International Congress of Anthropology and Prehistoric Archaeology of Paris. *American Naturalist*, 25: 1031-1032.
1895 Stone Cutting Implements. *The Archaeologist*, 3: 179-185.
1898 Beveled Arrowheads. *American Archaeologist*, 2: 141-143.
1899 Arrowpoints, Spearheads, and Knives of Prehistoric Times. *Report of the United States National Museum for 1897:* 811-988.
Windes, T. C. and C. M. Cameron
1981 *Chipped Stone and Ceramic Survey of Greenlee and Upper Kin Klizhin Ruins.* Ms. on file, National Park Service Chaco Archive, University of New Mexico, Albuquerque.
Wiseman, R. N.
1990 Raw Material Selection for Chipped Stone Artifacts in the Late Developmental Sites of the Santa Fe District. In, *Clues to the Past,* edited by M. S. Duran and D. T. Kirkpatrick, pp. 345-349. The Archaeological Society of New Mexico, Albuquerque.
Woodbury, Richard B.
1954 *Prehistoric Stone Implements of Northeastern Arizona.* Papers of the Peabody Museum of American Archaeology and Ethnology, Vol. 34. Harvard University, Cambridge, Massachusetts.
Yellen, John E.
1977 *Archaeological Approaches to the Present.* New York: Academic Press.
Young, David E. and Robson Bonnichsen
1984 Understanding Stone Tools: A Cognitive Approach. *Peopling of the Americas Series*: Vol. 1. Center for the Study of Early Man, University of Maine, Orono, Maine.

APPENDIX A: CLEMEXVISION PE BINARY IMAGES

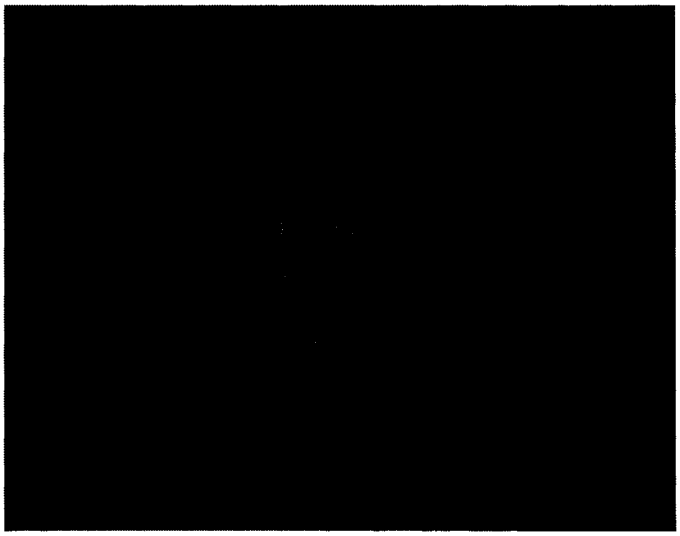


Figure A1: SJF used to scrape dry hide for 10 minutes.

Figure A2: SJF used to scrape dry hide for 30 minutes.

Figure A3: SJF used to scrape dry hide for 60 minutes.

Figure A4: BB used to scrape dry hide for 10 minutes.

Figure A5: BB used to scrape dry hide for 30 minutes.

Figure A6: BB used to scrape dry hide for 60 minutes.

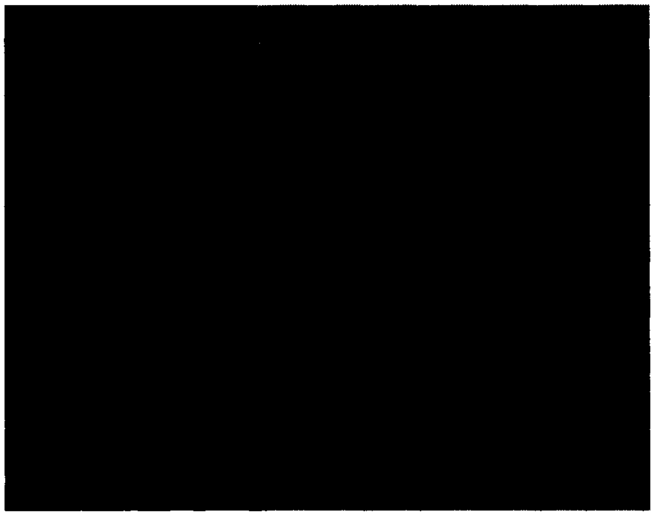


Figure A7: YSW used to scrape dry hide for 10 minutes.

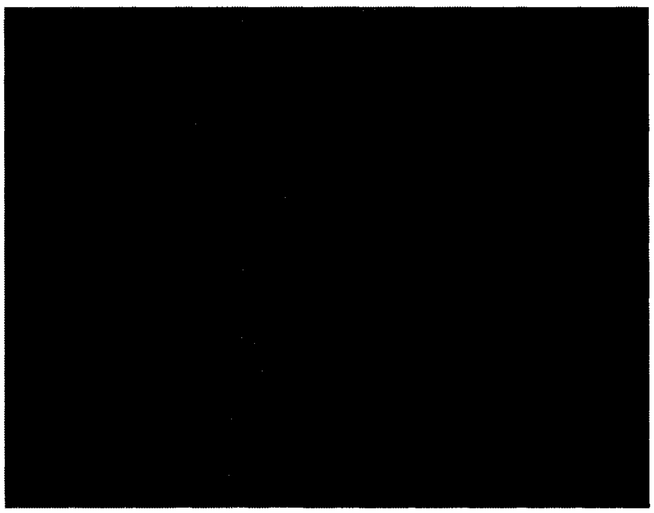


Figure A8: YSW used to scrape dry hide for 30 minutes.

Figure A9: YSW used to scrape dry hide for 60 minutes.

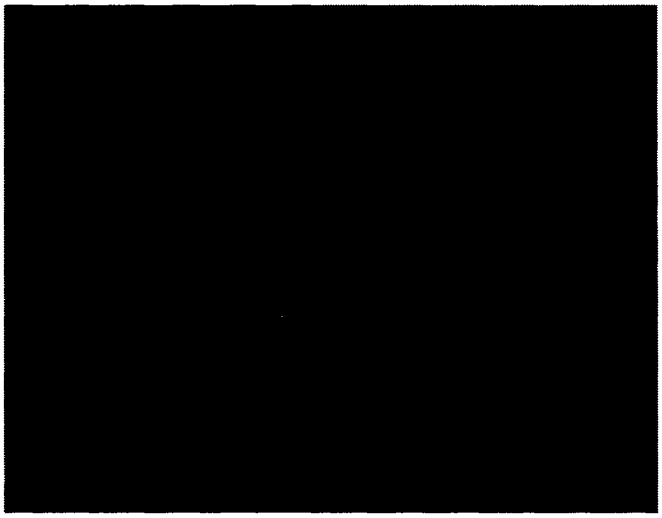


Figure A10: MUG used to scrape dry hide for 10 minutes.

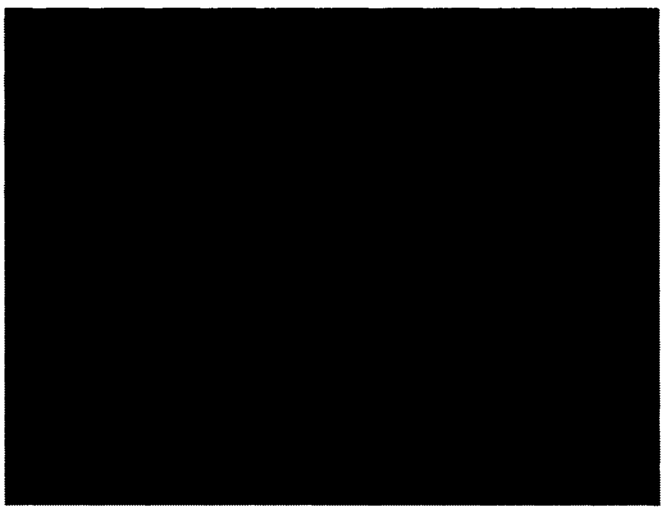


Figure A11: MUG used to scrape dry hide for 30 minutes.

Figure A12: MUG used to scrape dry hide for 60 minutes.

Figure A13: SJF used to scrape fresh hide for 10 minutes.

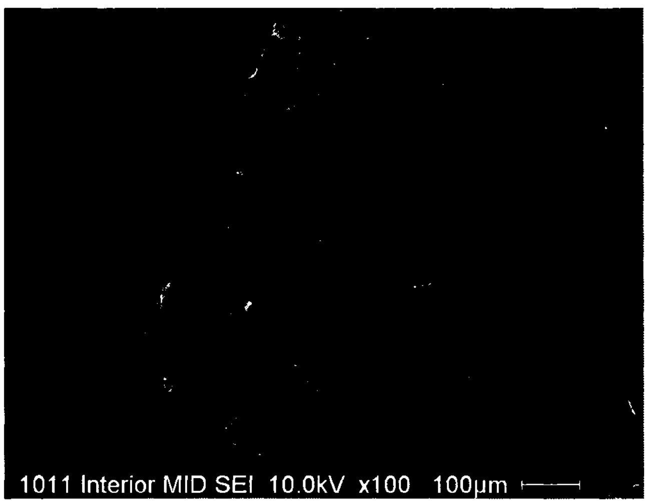


Figure A14: SJF used to scrape fresh hide for 30 minutes.

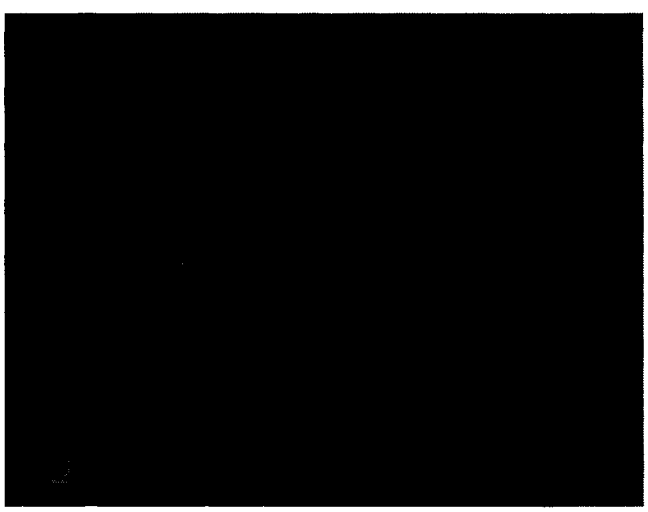


Figure A15: SJF used to scrape fresh hide for 60 minutes.

Figure A16: BB used to scrape fresh hide for 10 minutes.

Figure A17: BB used to scrape fresh hide for 30 minutes.

Figure A18: BB used to scrape fresh hide for 60 minutes.

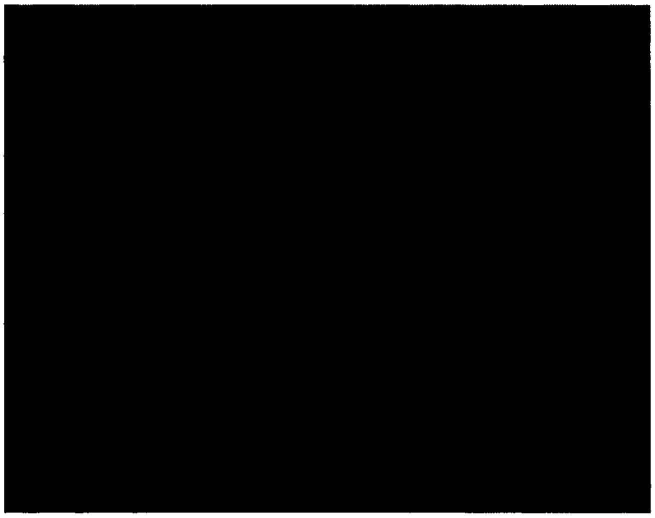


Figure A19: YSW used to scrape fresh hide for 10 minutes.

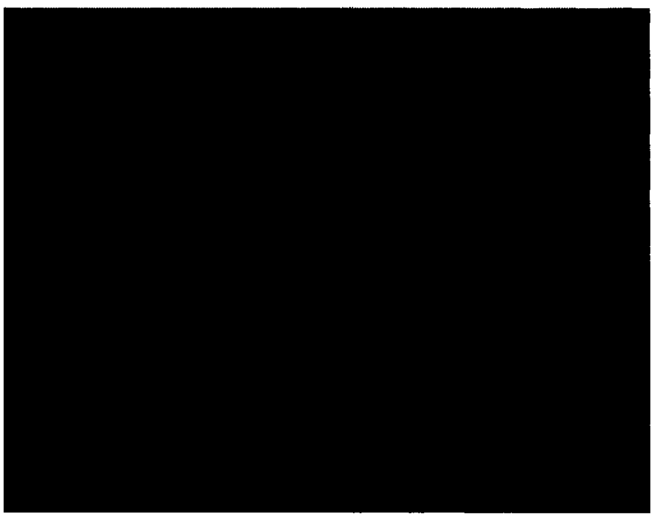


Figure A20: YSW used to scrape fresh hide for 30 minutes.

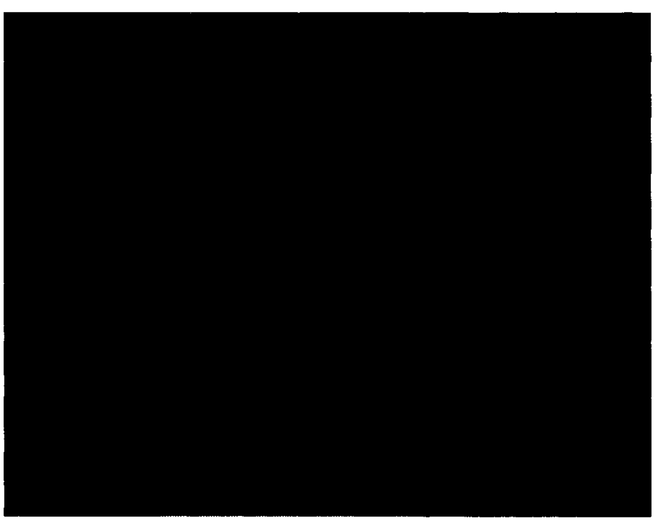


Figure A21: YSW used to scrape fresh hide for 60 minutes.

Figure A22: MUG used to scrape fresh hide for 10 minutes.

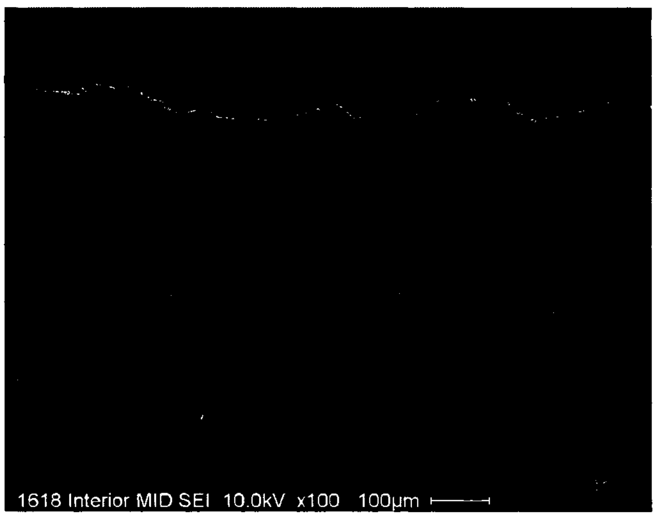


Figure A23: MUG used to scrape fresh hide for 30 minutes.

Figure A24: MUG used to scrape fresh hide for 60 minutes.

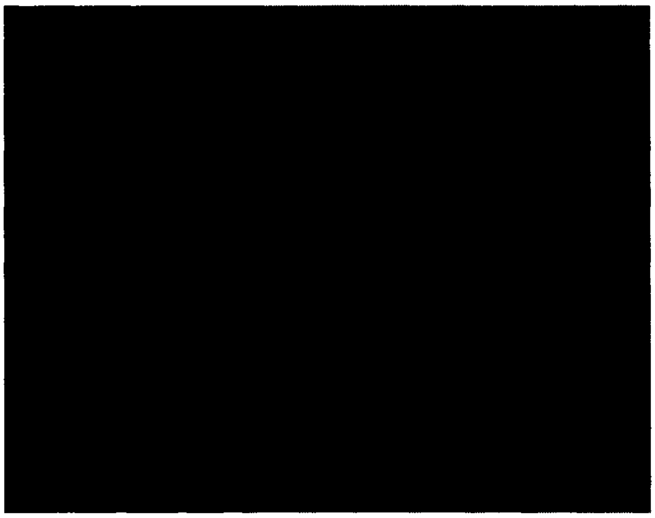


Figure A25: SJF used to plane juniper wood for 10 minutes.

Figure A26: SJF used to plane juniper wood for 30 minutes.

Figure A27: SJF used to plane juniper wood for 60 minutes.

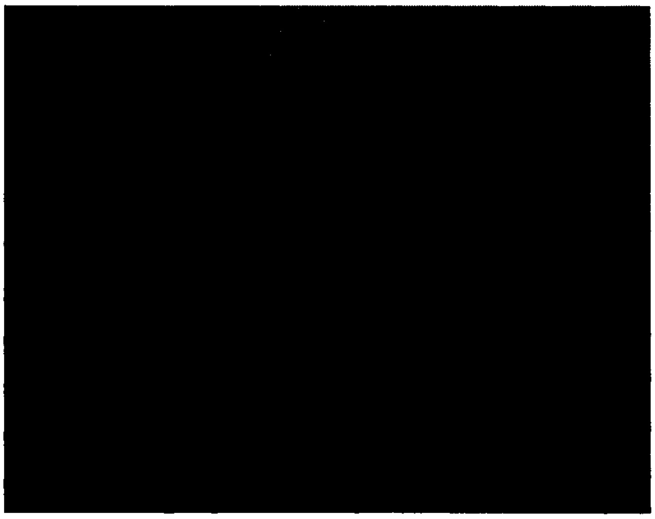


Figure A28: BB used to plane juniper wood for 10 minutes.

Figure A29: BB used to plane juniper wood for 30 minutes.

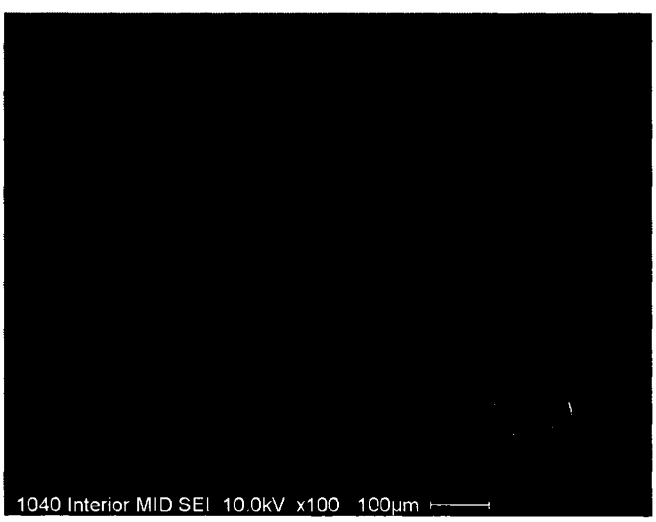


Figure A30: BB used to plane juniper wood for 60 minutes.

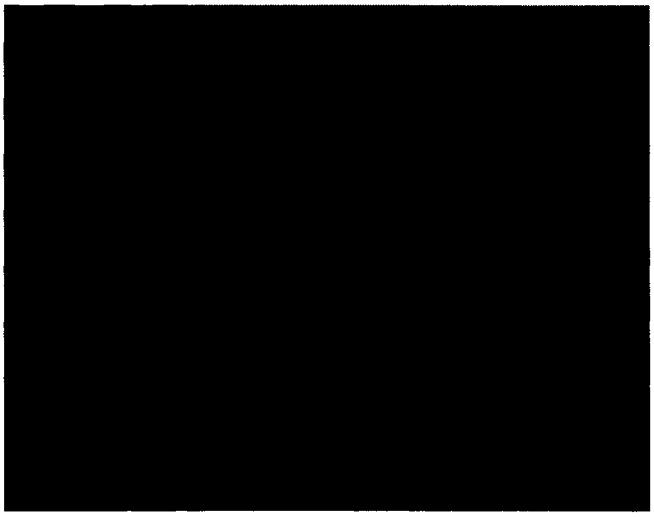


Figure A31: YSW used to plane juniper wood for 10 minutes.

Figure A32: YSW used to plane juniper wood for 30 minutes.

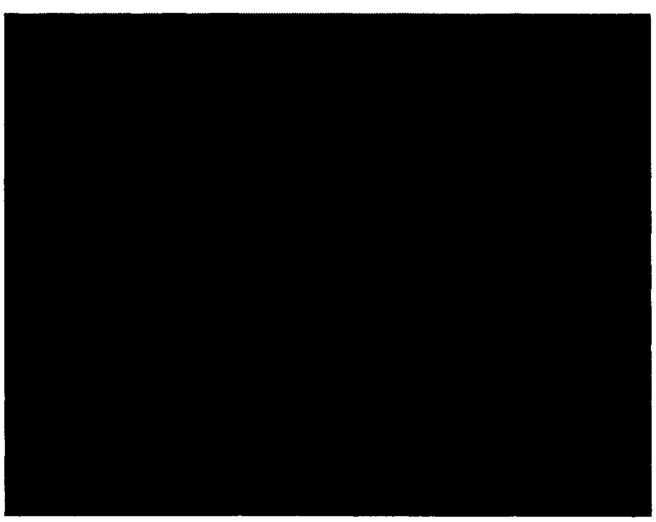


Figure A33: YSW used to plane juniper wood for 60 minutes.

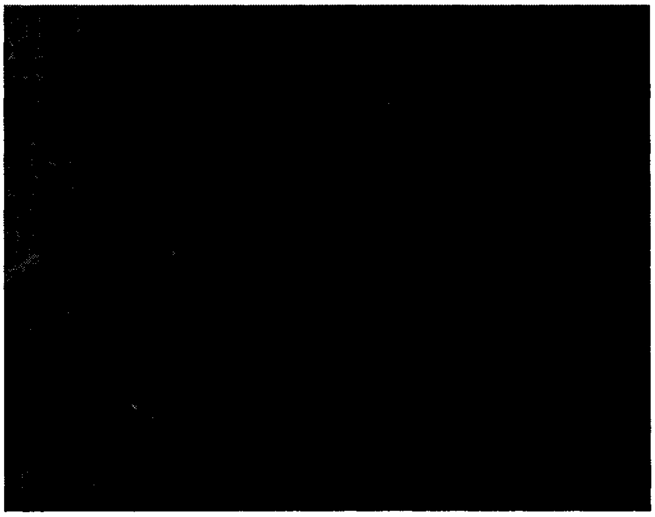


Figure A34: MUG used to plane juniper wood for 10 minutes.

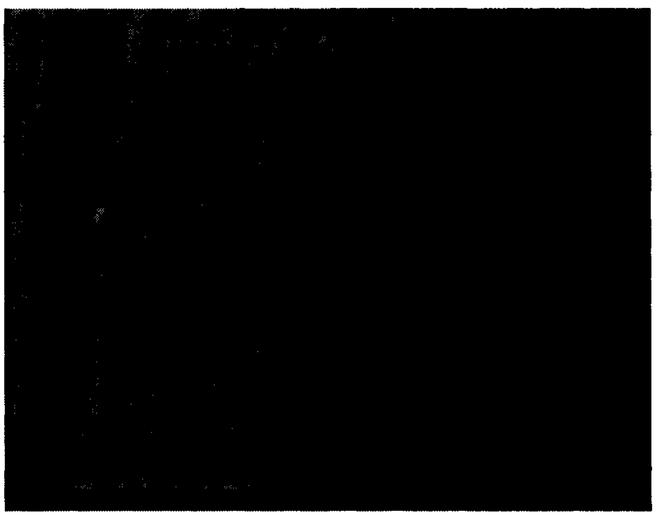


Figure A35: MUG used to plane juniper wood for 30 minutes.

Figure A36: MUG used to plane juniper wood for 60 minutes.

Figure A37: SJF used to scrape dry hide for 10 minutes (2nd set).

Figure A38: SJF used to scrape dry hide for 30 minutes (2nd set).

Figure A39: SJF used to scrape dry hide for 60 minutes (2nd set).

Figure A40: BB used to scrape dry hide for 10 minutes (2nd set).

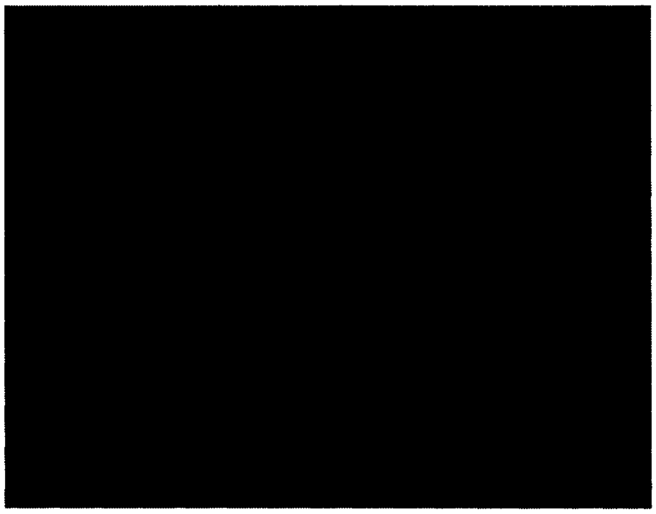


Figure A41: BB used to scrape dry hide for 30 minutes (2nd set).

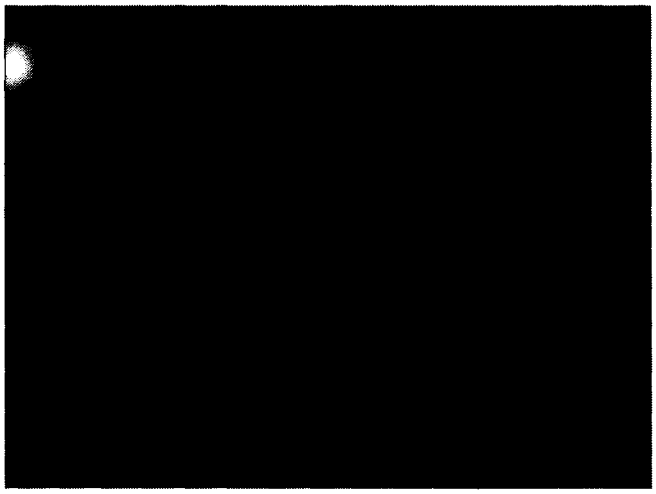


Figure A42: BB used to scrape dry hide for 60 minutes (2nd set).

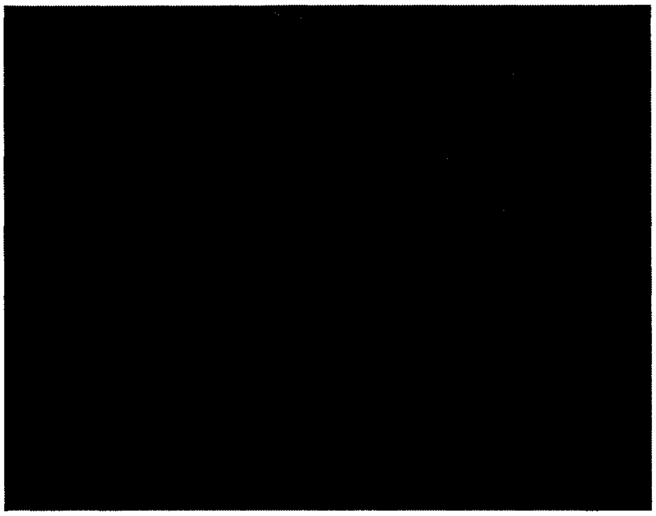


Figure A43: YSW used to scrape dry hide for 10 minutes (2nd set).

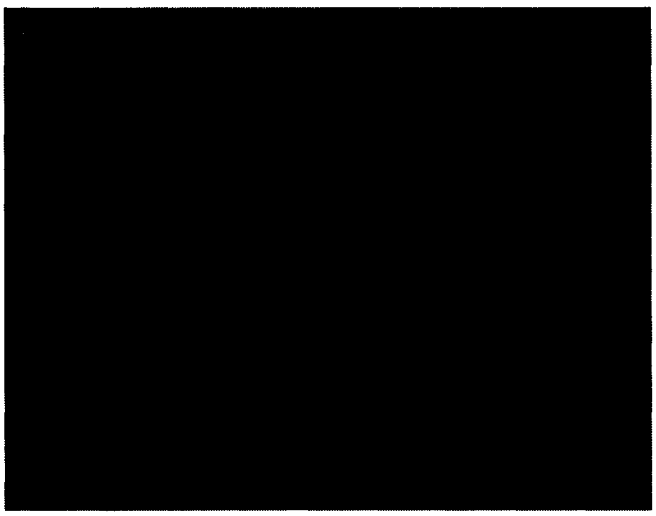


Figure A44: YSW used to scrape dry hide for 30 minutes (2nd set).

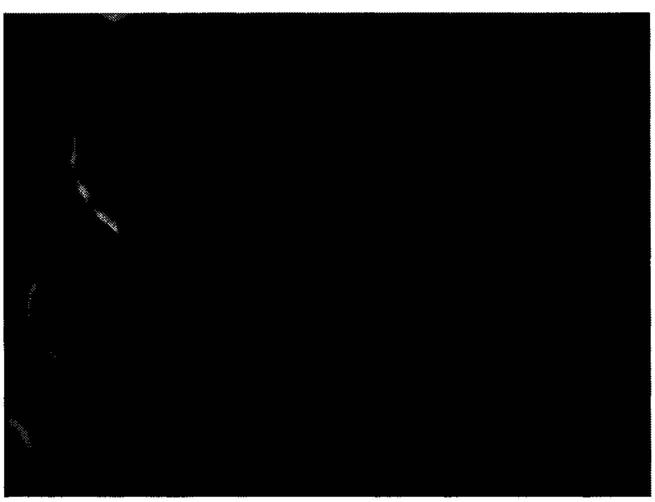


Figure A45: YSW used to scrape dry hide for 60 minutes (2nd set).

Figure A46: MUG used to scrape dry hide for 10 minutes (2nd set).

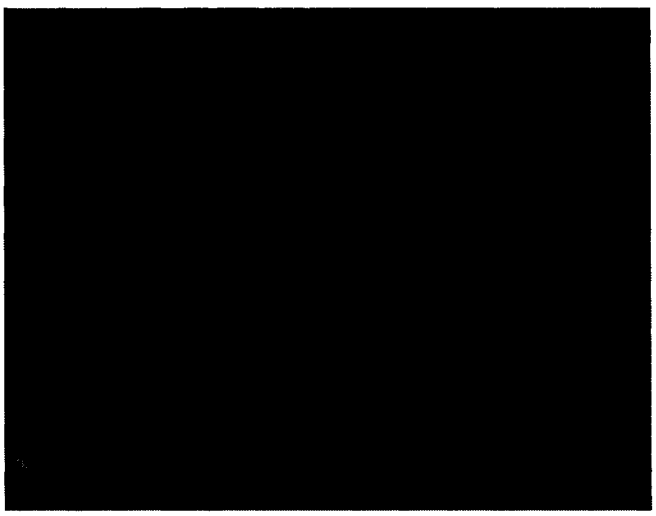


Figure A47: MUG used to scrape dry hide for 30 minutes (2nd set).

Figure A48: MUG used to scrape dry hide for 60 minutes (2nd set).

Figure A49: SJF FS 898 from FA2-13.

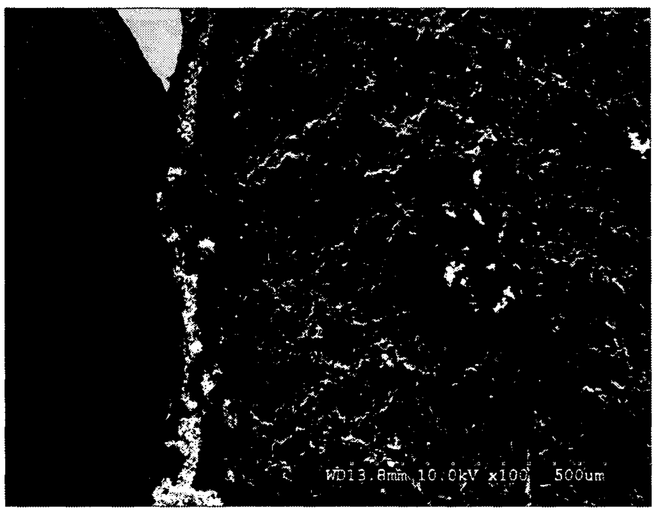


Figure A50: SJF FS 1032 from FA2-13.

Figure A51: SJF FS 1082 from FA2-13.

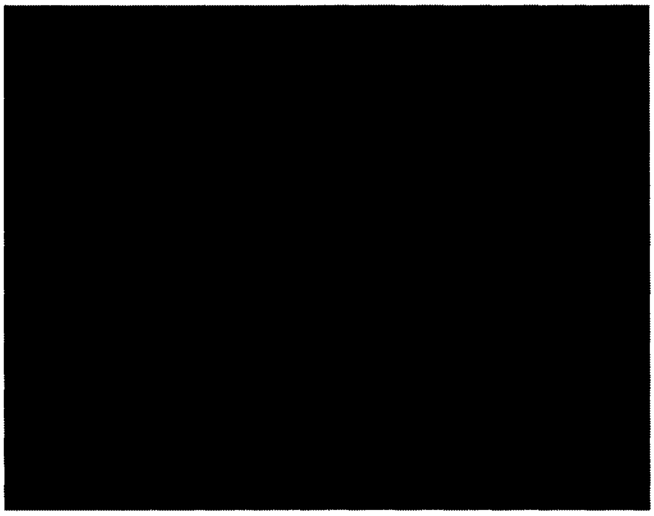


Figure A52: SJF FS 1087
from FA2-13.

Figure A53: SJF FS 1137
from FA2-13.

Figure A54: YSW FS 1040
from FA2-13.

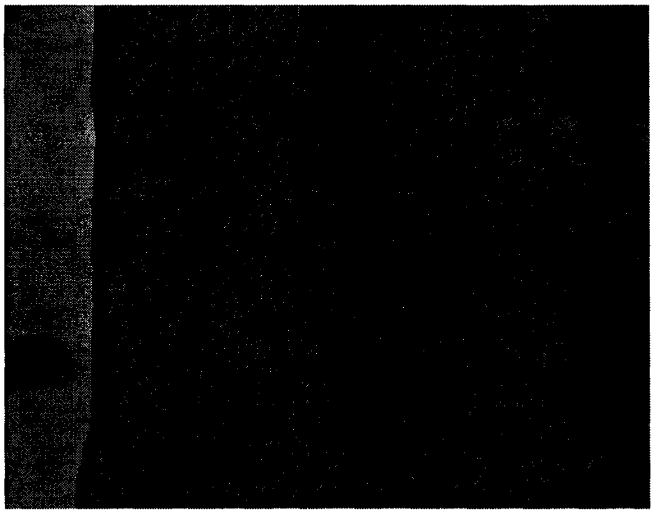


Figure A55: YSW FS 1059 from FA2-13.

Figure A56: SJF FS 1131 from FA2-13.

Figure A57: YSW FS 1149 from FA2-13.

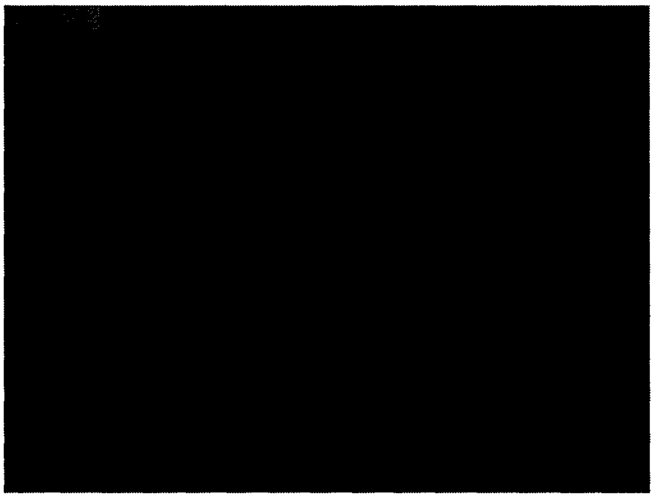
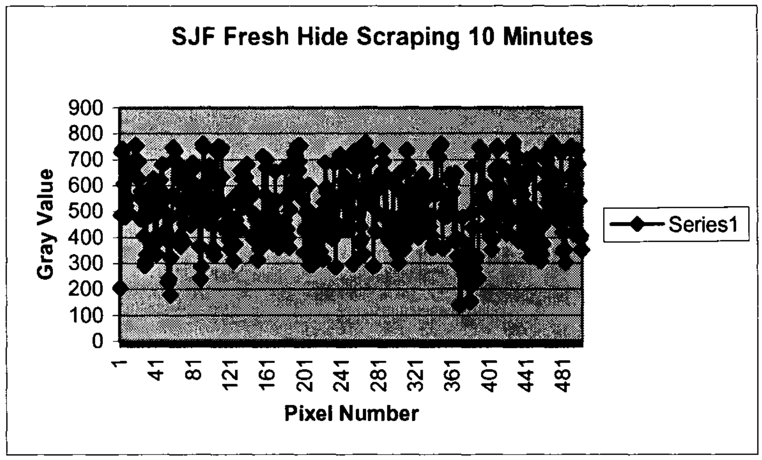


Figure A58: YSW FS 1156 from FA2-13.

(All images are at 100x unless otherwise specified.)

APPENDIX B: IDRISI GIS LINE GRAPHS OF TOOL SURFACE MICROTOPOGRAPHY



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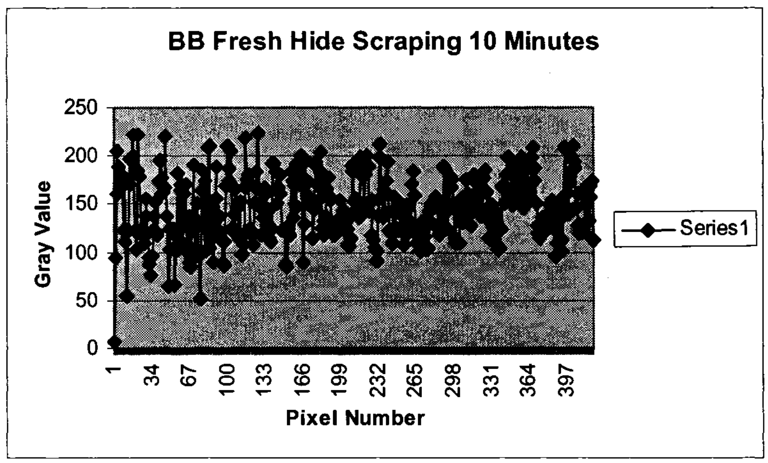


Figure B.2

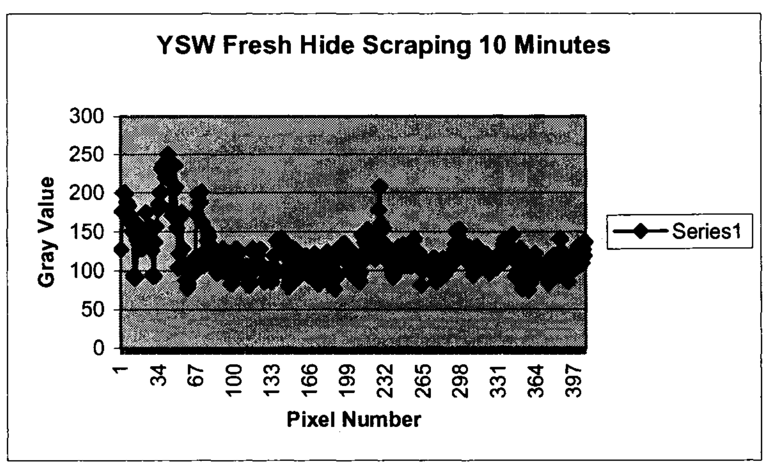
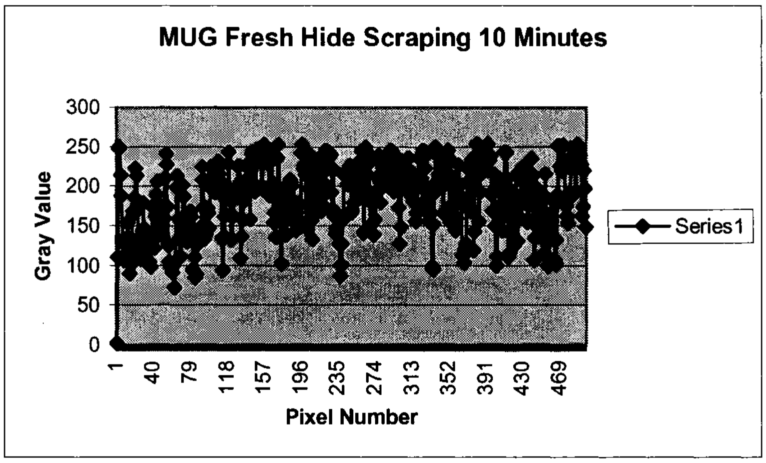


Figure B.3



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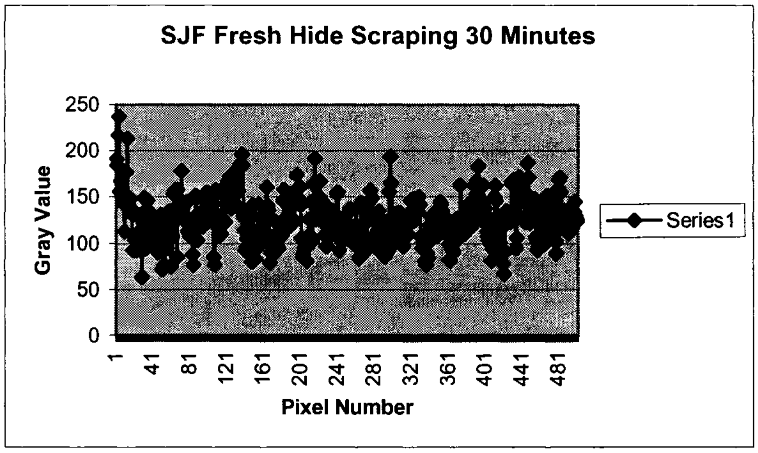

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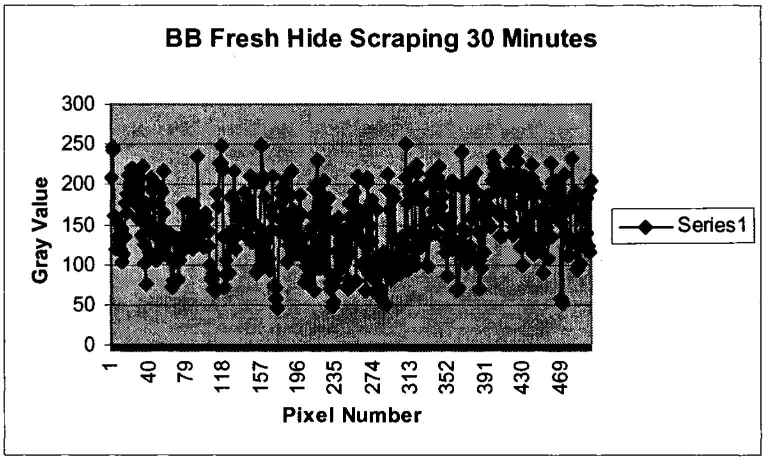

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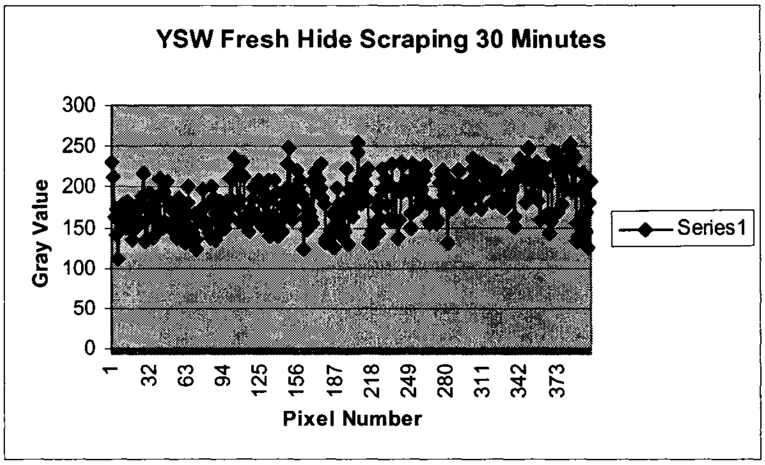

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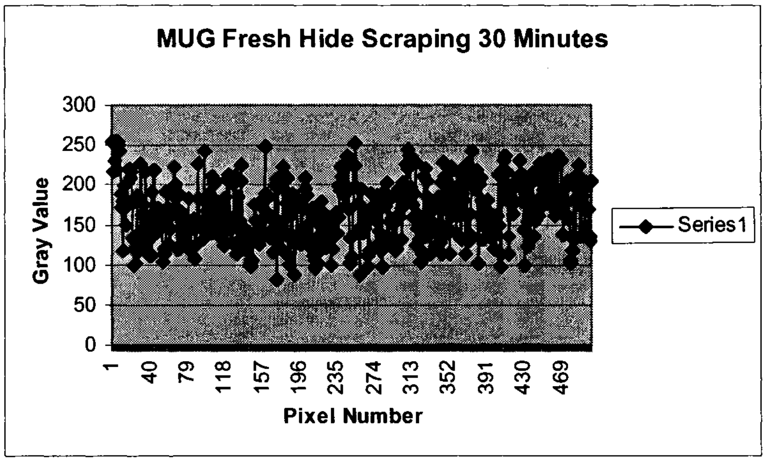

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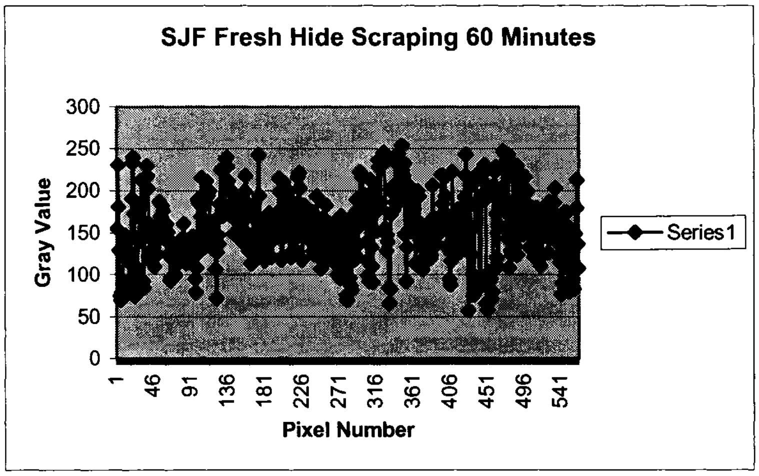

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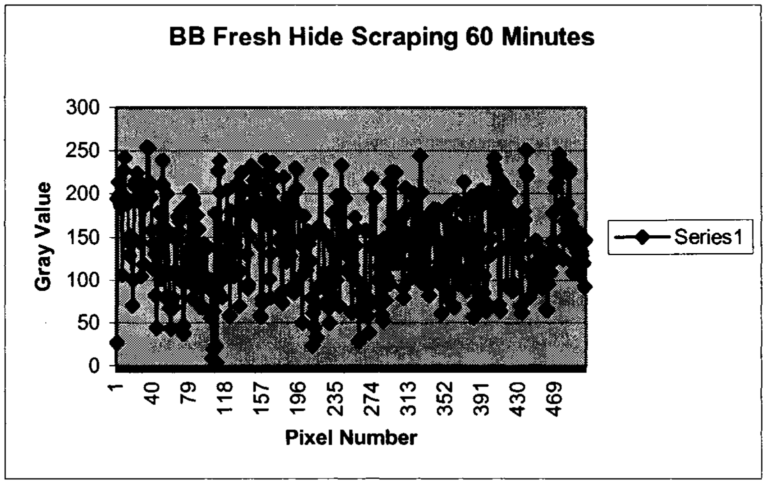

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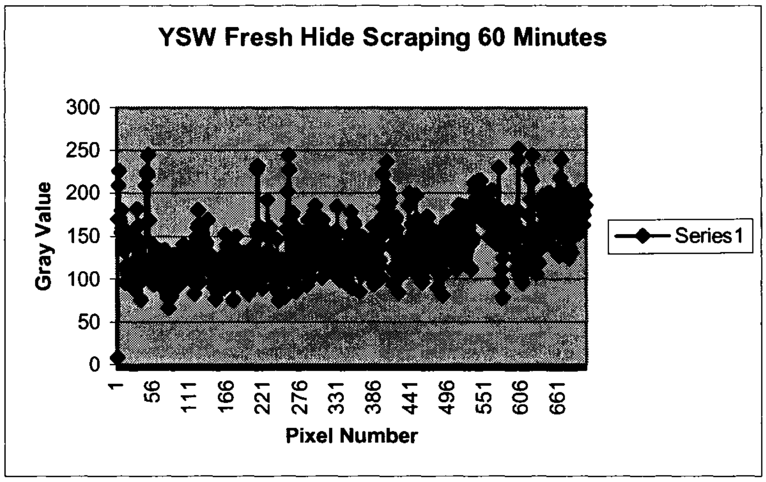

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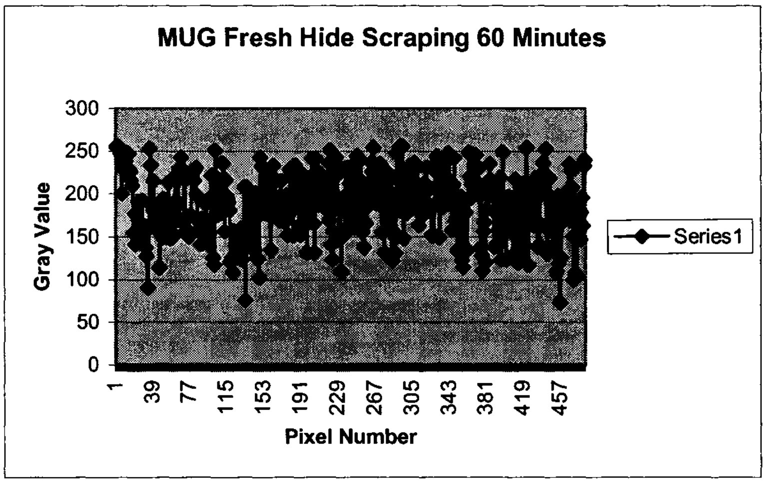

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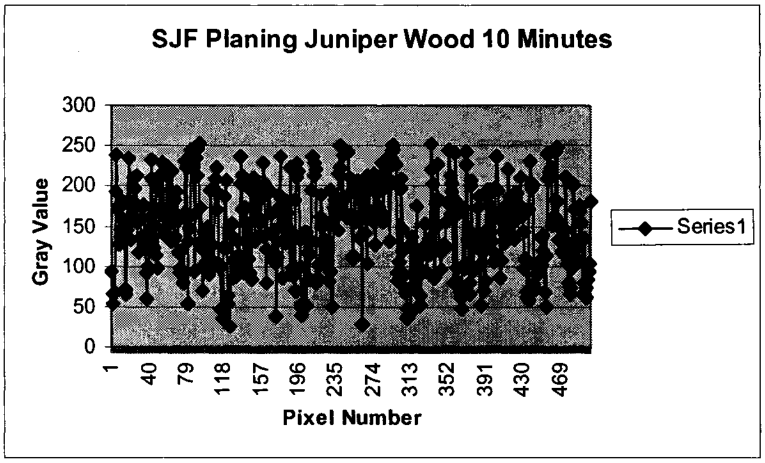

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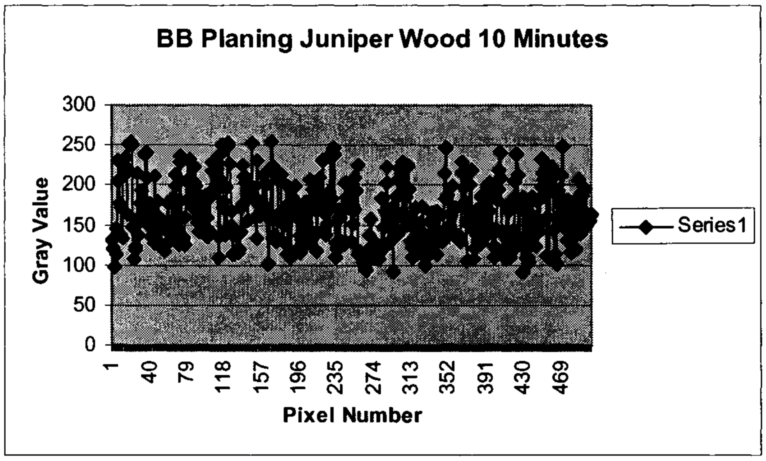

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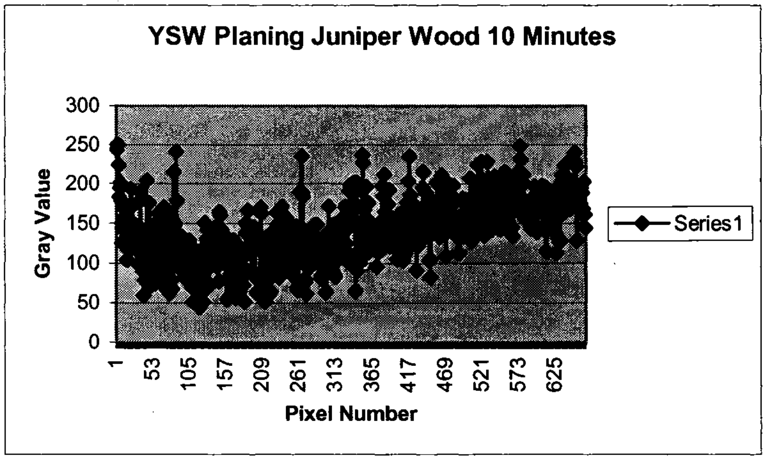

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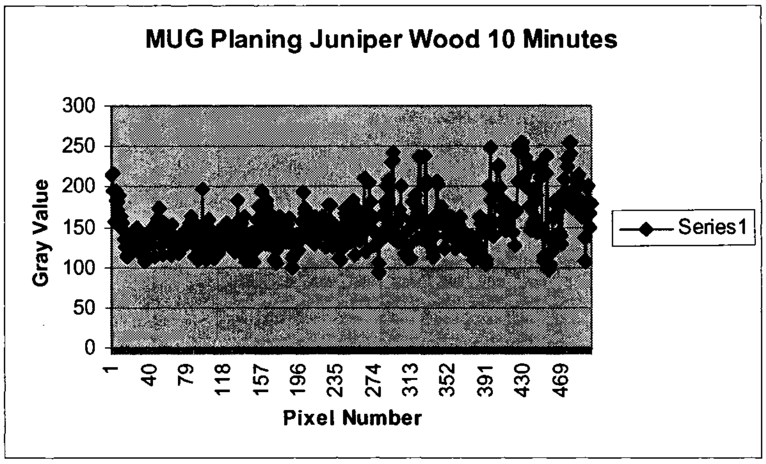

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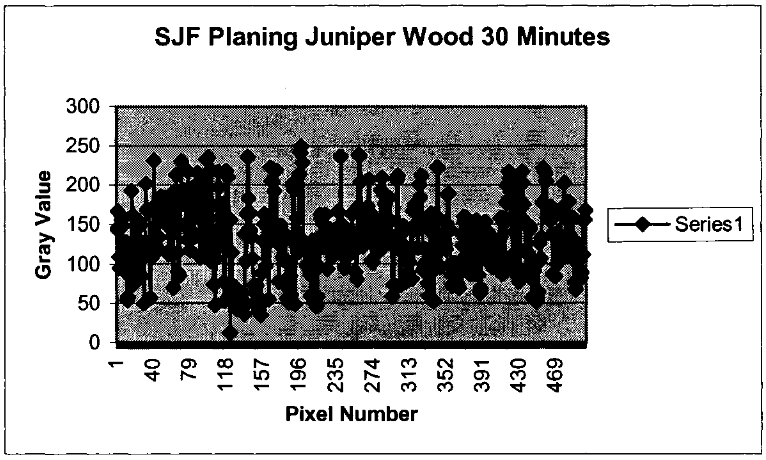

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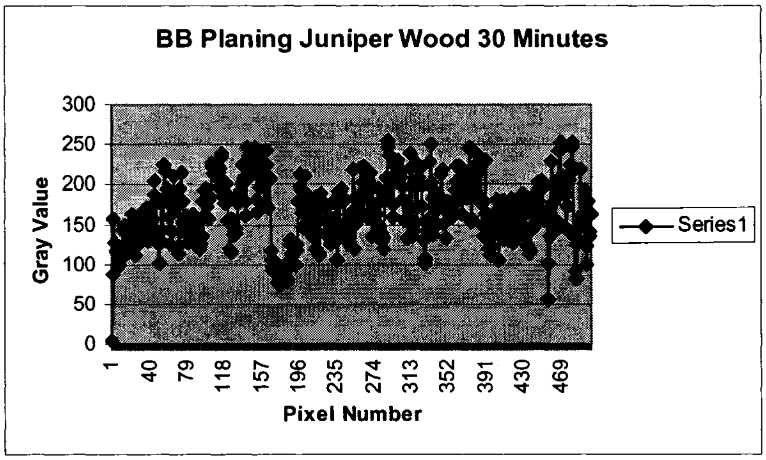

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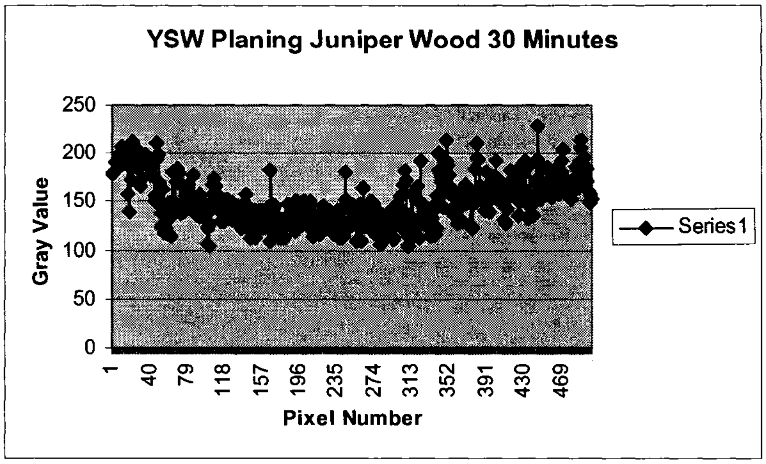

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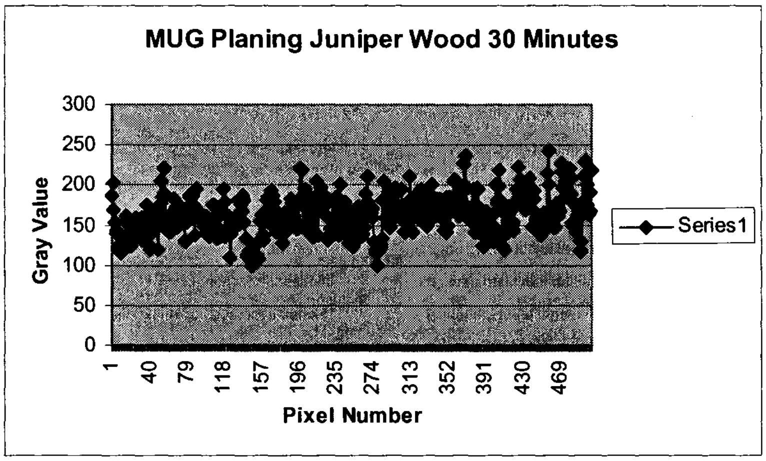

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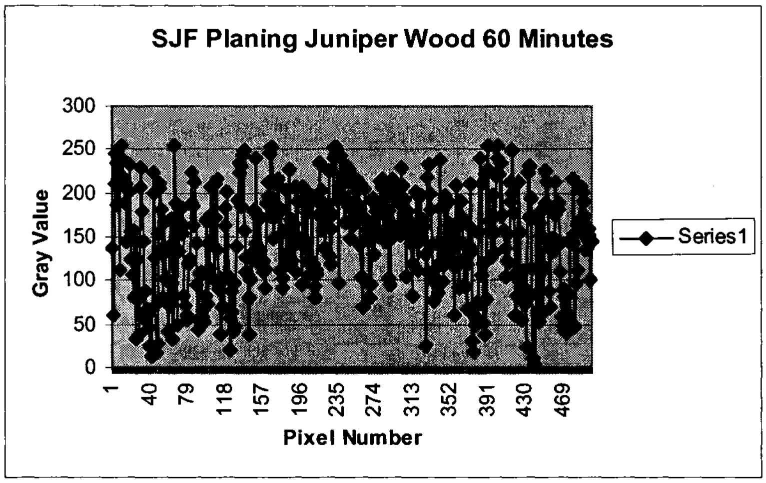

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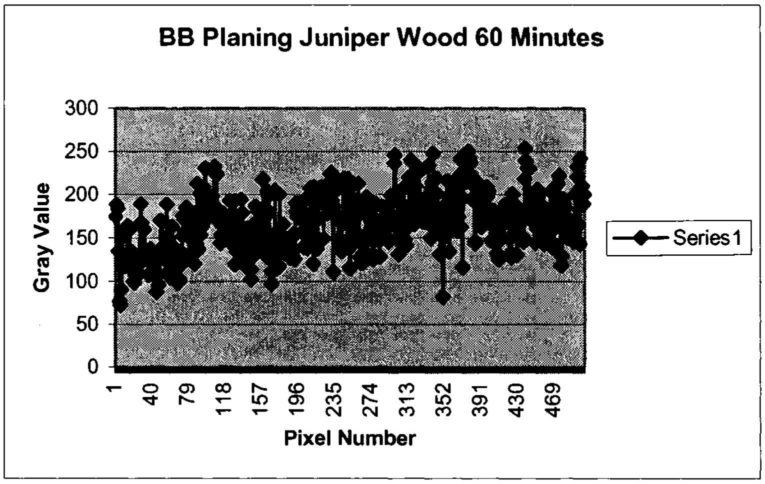

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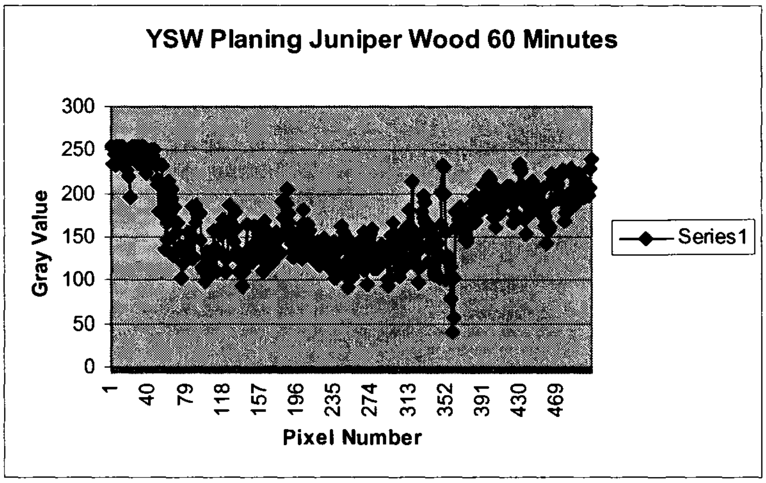

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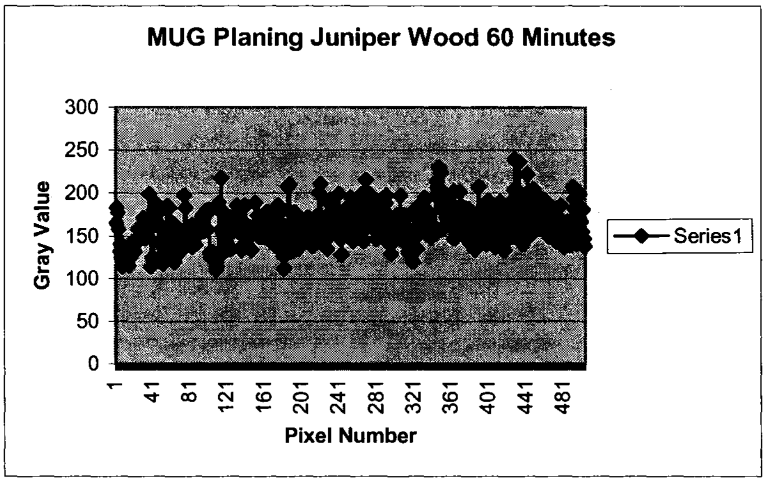

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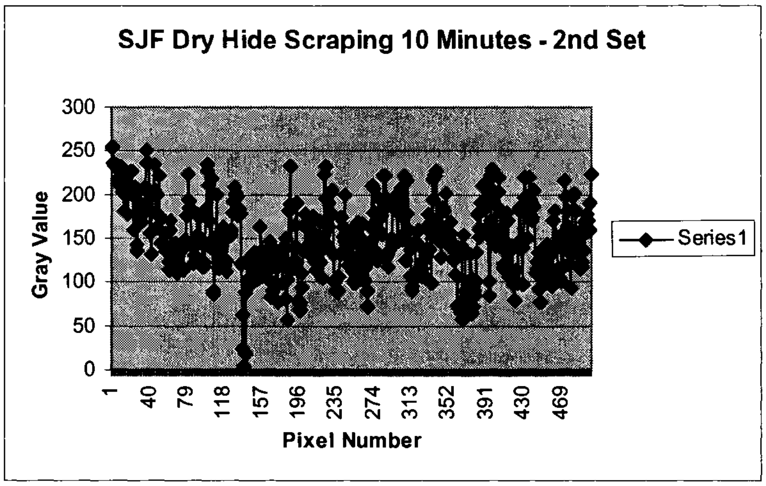

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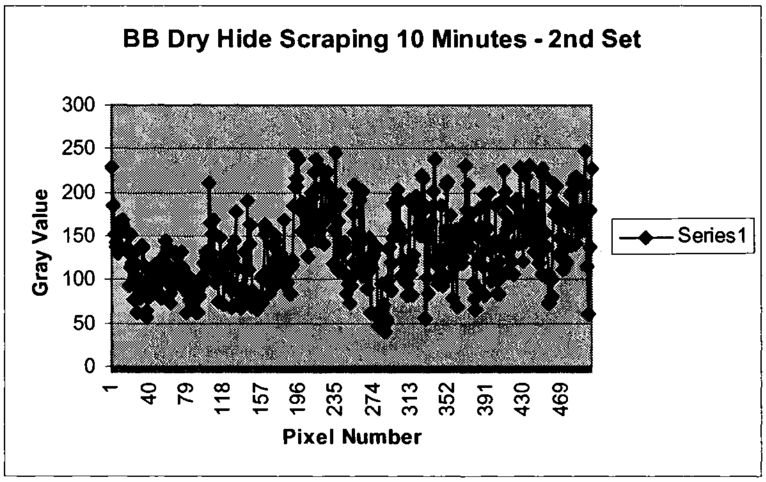

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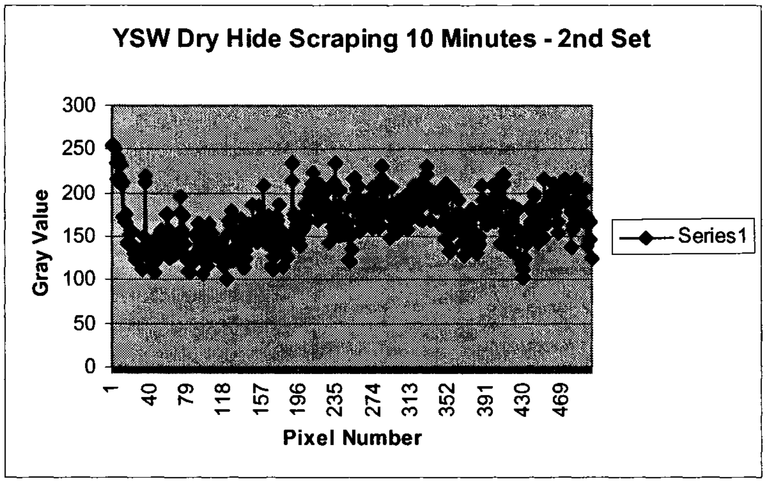

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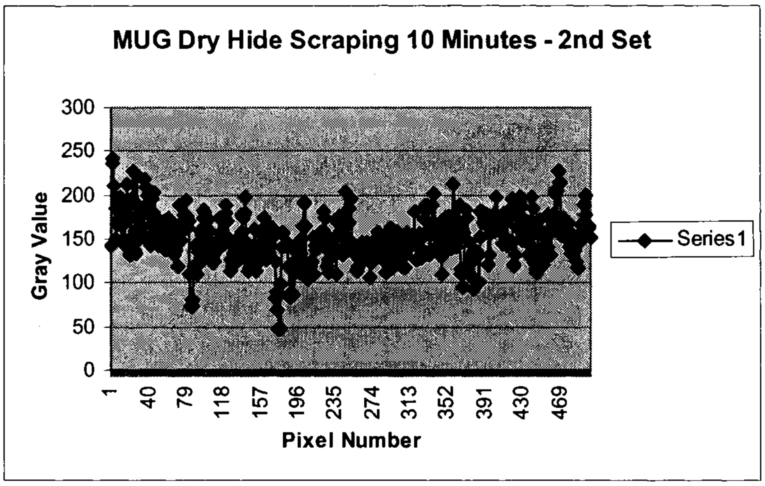

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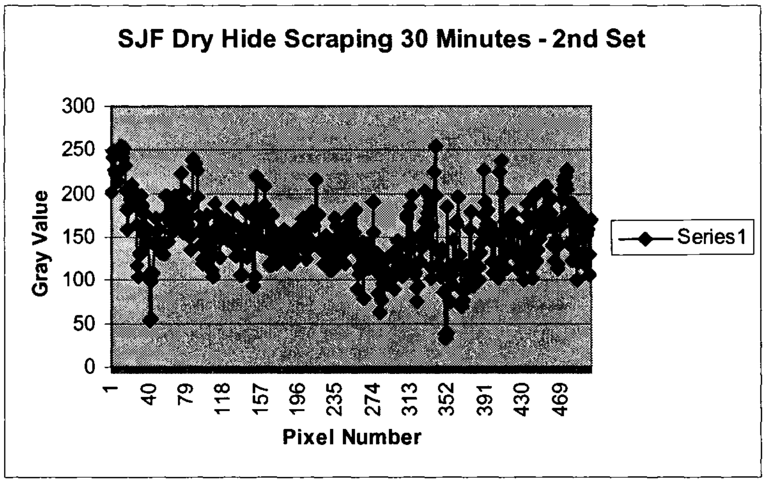

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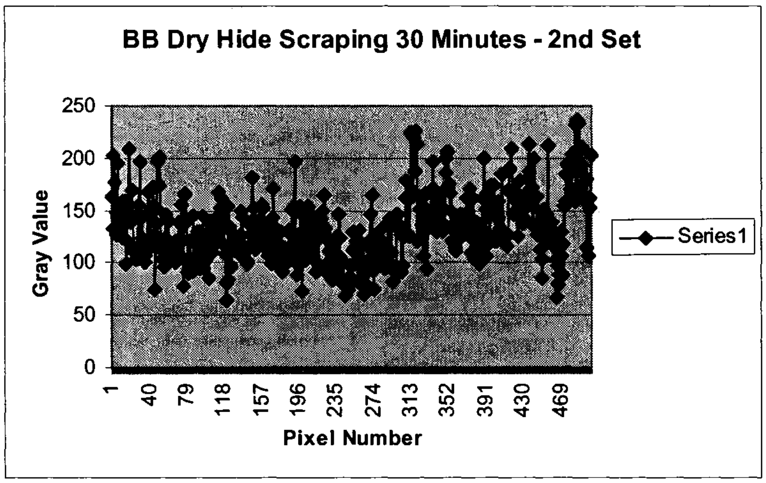

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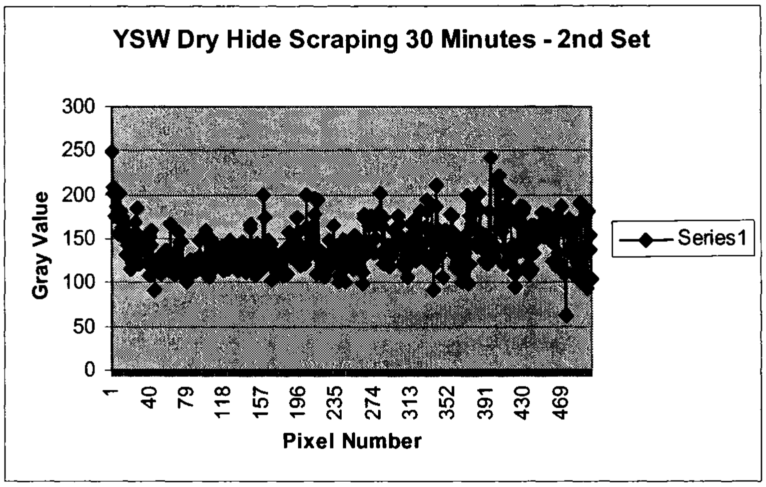

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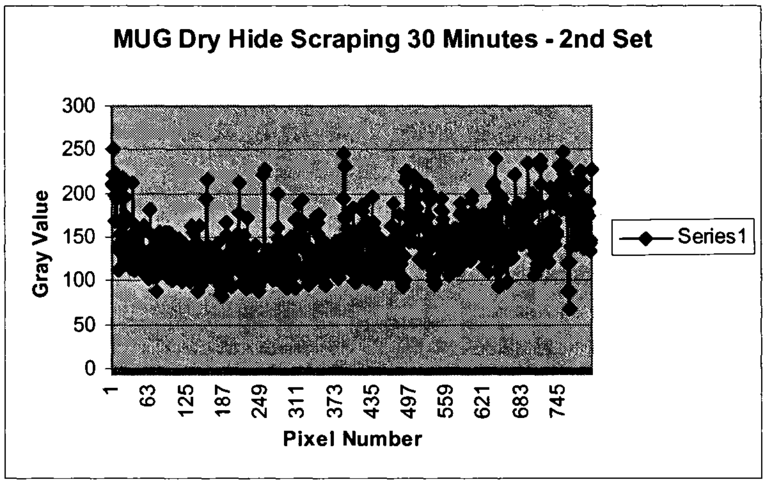

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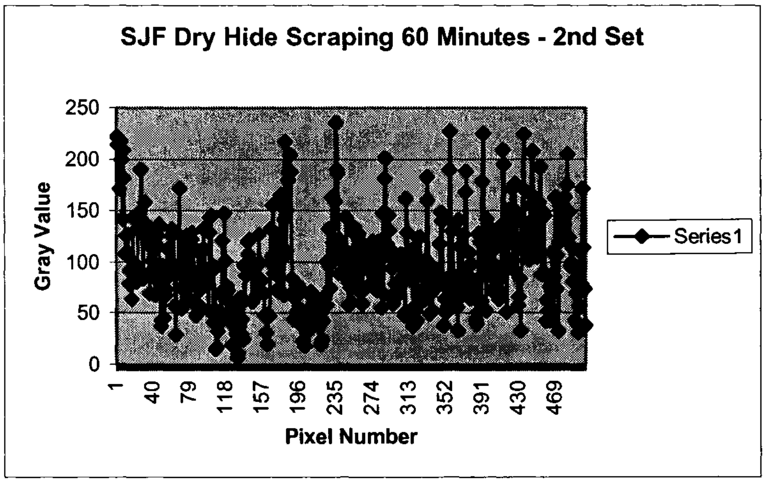

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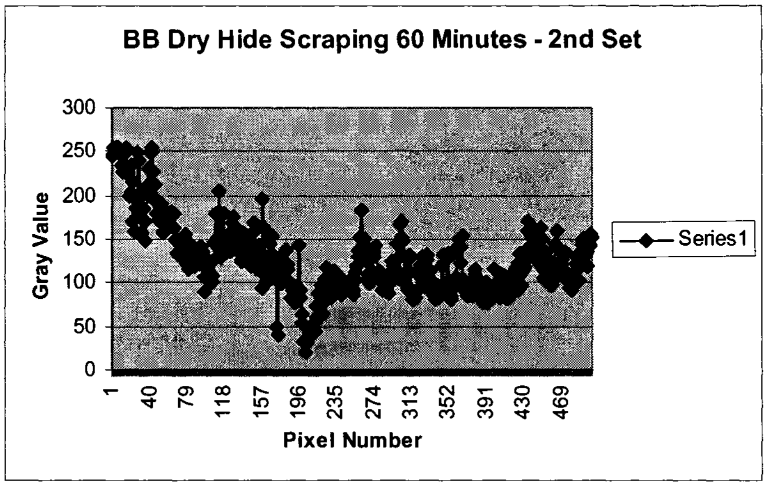

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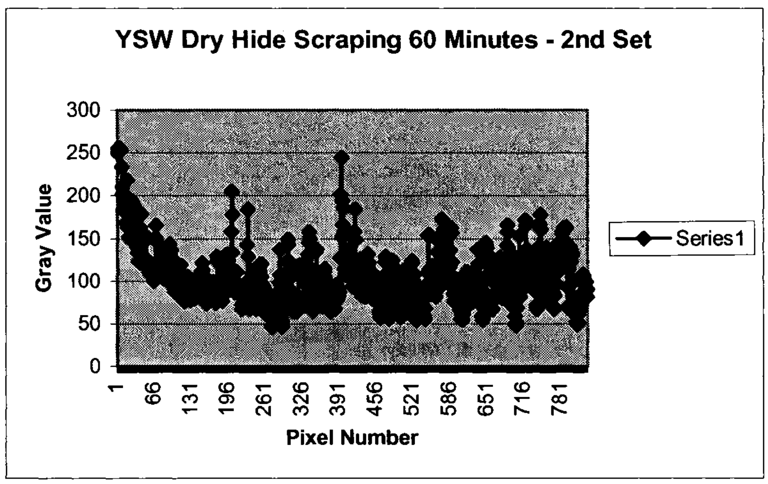

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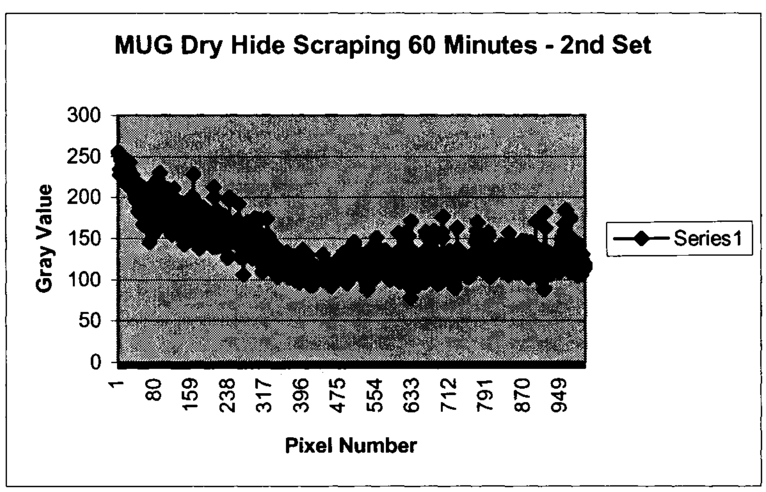

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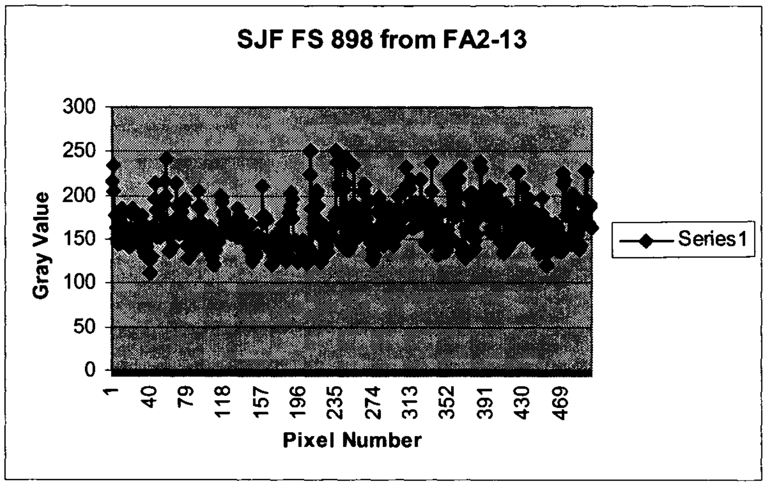

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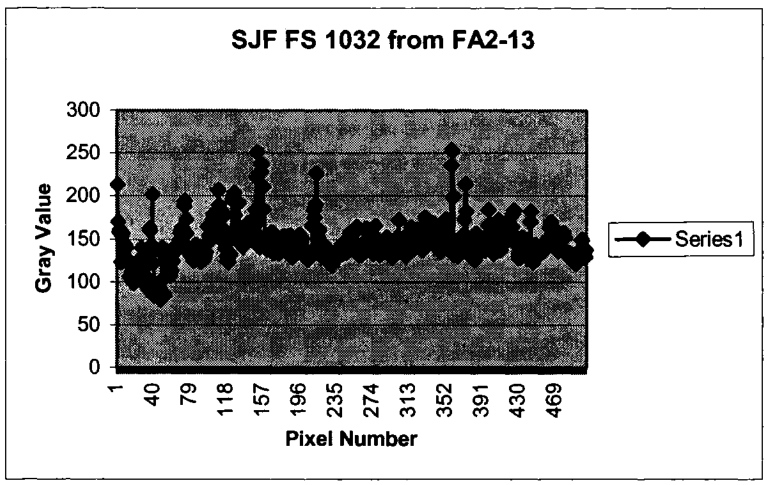

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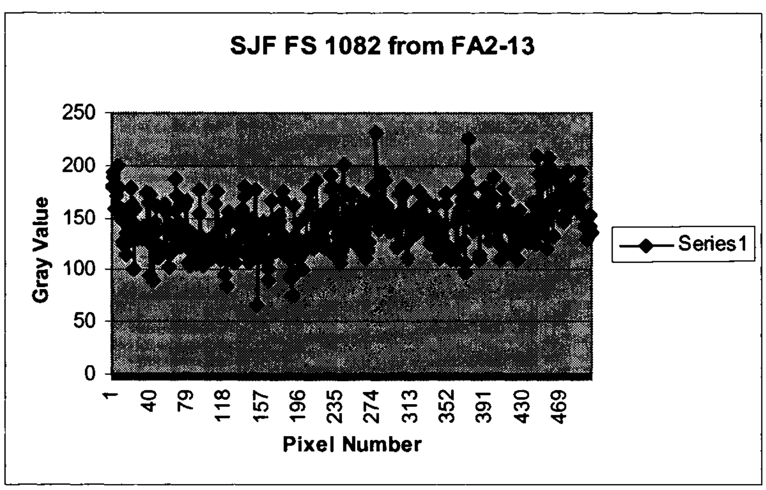

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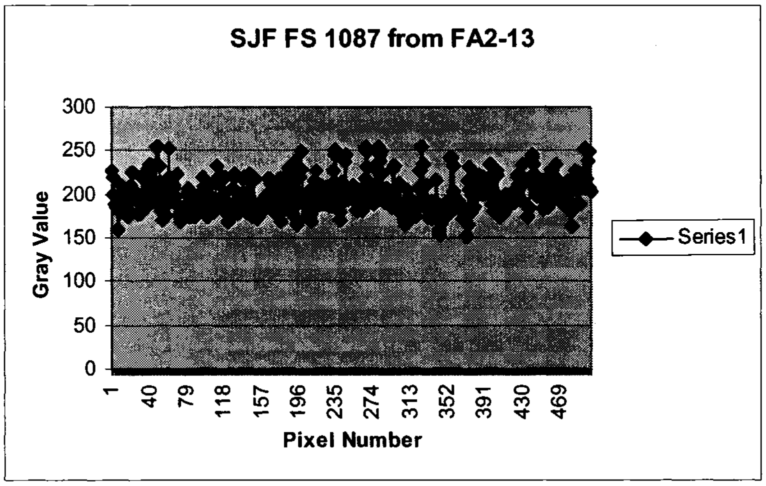

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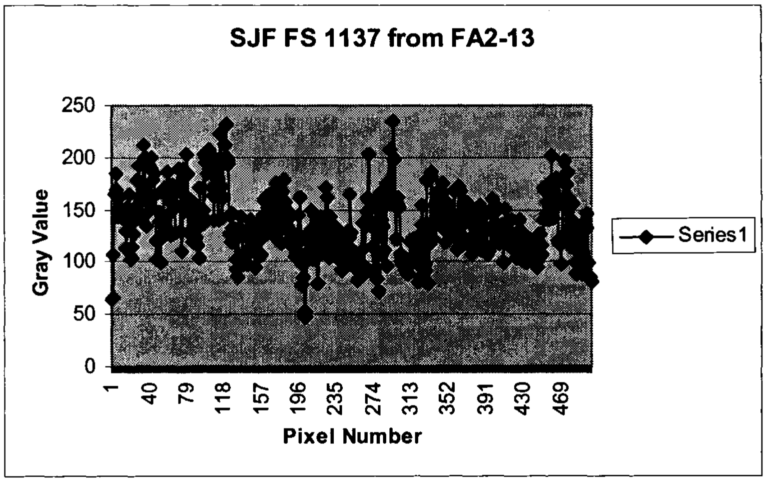

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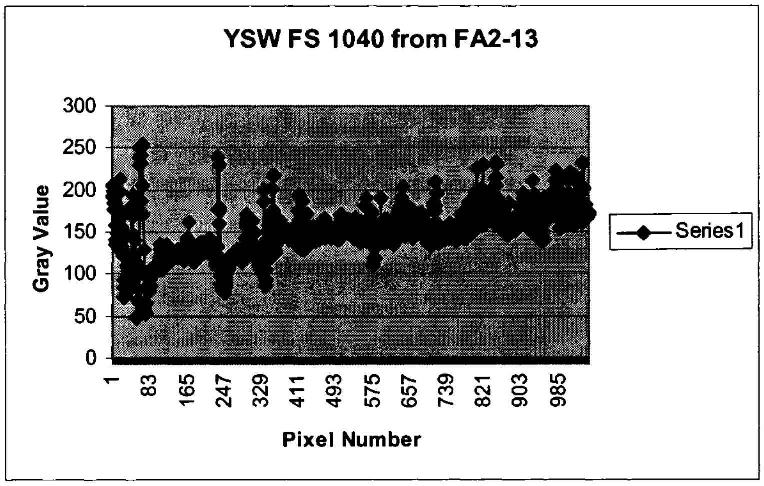

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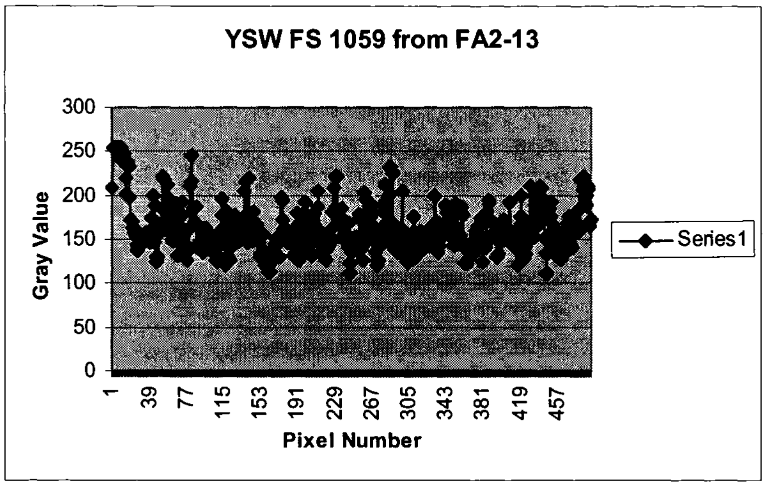

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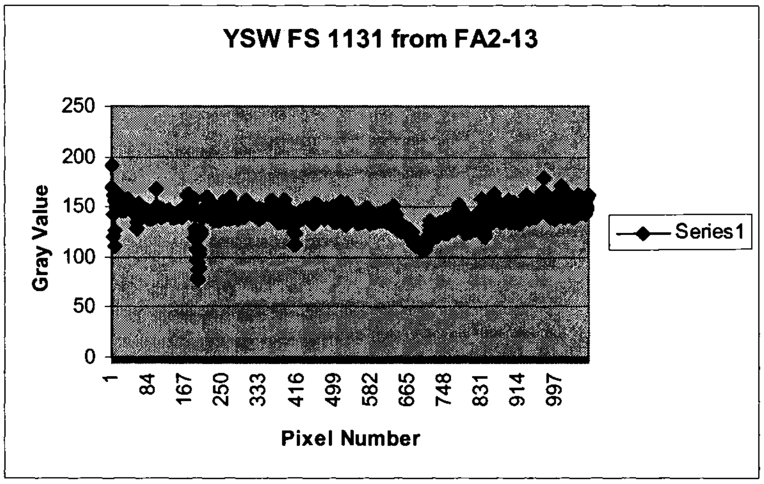


Figure B.44

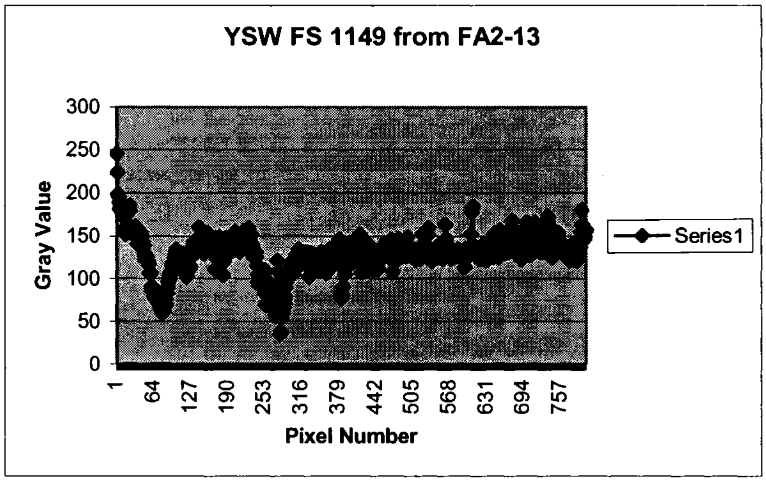
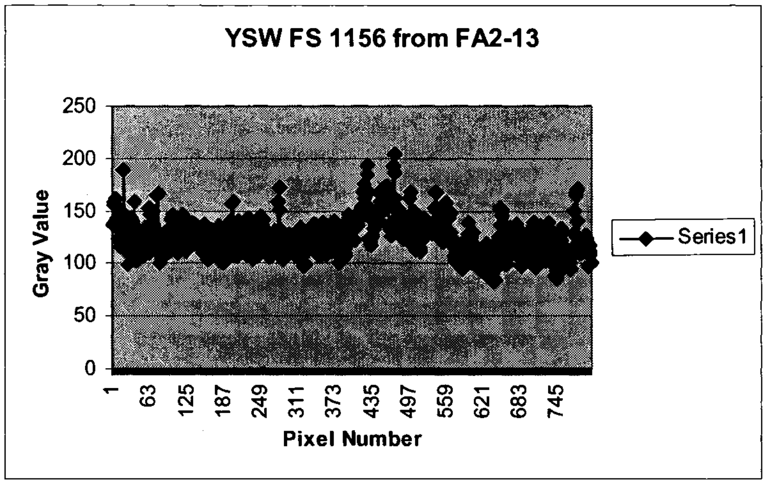


Figure B.45


YSW FS 1156 from FA2-13
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200
150
100
50
0
Gray Value
1
63
125
187
249
311
373
435
497
559
621
683
745
Pixel Number
Series1

Figure B.46

APPENDIX C: WAIVER FOR COPYRIGHTED MATERIAL

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File Code: 2360
Date: March 27, 2006

Mr. Harry Lerner
1059 Riverside Drive
London, Ontario
CANADA N6H2T4

Dear Mr. Lerner:

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Sincerely,

JUDITH G. PROPPER
Regional Archaeologist

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Figure C.1: Waiver for reproduction of Figures 5.3 and 5.4 for inclusion in this dissertation.