AN EXPERIMENTAL EVALUATION OF THE PRINCIPLES AND FRAMEWORKS FOR INTERPRETING THE FUNCTION OF ARCHAEOLOGICAL STONE ARTEFACTS

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A thesis submitted in total fulfillment of the requirements for the Degree of Doctor of Philosophy of The Australian National University.

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Except where otherwise stated in the text, this thesis is based entirely on my own research.

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In loving memory of my father
   Michael F. Collins
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   whom we miss every day.
ABSTRACT
The ability to understand and identify the functions of stone artefacts recovered from archaeological assemblages has been a long term goal of lithic technologists and archaeologists worldwide. As one of the primary means by which prehistoric hunter-gatherers negotiated the environment around them, understanding stone artefact functions is central to understanding and reconstructing the prehistoric subsistence and settlement patterns that depended upon them and, therefore, to meeting the objectives of archaeology as a field. Two broad approaches to inferring stone artefact function currently dominate the literature. The first examines macro- and microscopic use-wear preserved on archaeological specimens, seeking to identify specific artefact functions through analogies with experimental replication of hypothesized prehistoric tasks. The second approach explores stone artefact function within a broader, behavioural context, hypothesizing that tools functioned as a means of increasing efficiency in subsistence strategies by reducing the costs associated with resource procurement, through the organisation of technology. Both approaches have gained widespread acceptance within the discipline and form the basis of countless interpretations of archaeological sites worldwide. Yet, to date, neither approach has been systematically evaluated and tested. Such an evaluation forms the basis of the research presented here.

Evaluation of the principles underlying each approach reveals their dependence upon a number of untested assumptions about stone artefact function. In particular, the relationship between artefact morphology and function is revealed to be based largely upon assumed, rather than demonstrated, knowledge of stone tool use. Failure to explore the key area of performance in investigations of artefact function and to identify the morphological attributes responsible for stone artefact performance, has contributed to technologists’ current inability to explain the relationship between form and function in stone artefacts.

The controlled experimental program carried out in this thesis was designed to address these issues, both by systematically testing the interpretive ability of the current frameworks for identifying stone artefact function and also by exploring the relationship between artefact form and function through an understanding of stone artefact performance. The results contradict many previous assumptions, revealing a number of misconceptions in current views on the identification and interpretation of stone artefact function. The inability to identify unique signatures for particular artefact functions in the patterns of use-scarring produced through artefact use, demonstrated in this thesis, indicates that a
consistent relationship between use and the scarring-wear produced does not exist. Instead, the features of scars produced through use are shown to be the product of multiple complex interactions between previously untested variables and relate to both use and the morphological features of the working edge. This observation is a direct contradiction of the principles upon which wear analyses are based and, necessarily, calls into question the interpretive value of this technique. Likewise, the illustration that form and function are not uniquely connected challenges current assumptions that equate morphological difference with difference in functional utility. Instead, it is demonstrated that stone artefact manufacture and performance are responsive to a wide range of interactions between use and morphological variables, which allows them to respond to different circumstances by compromising forms, balancing trade-offs and performing a wide range of functions. The emerging view of the relationship between artefact form and function is that of a dynamic and interactive system in which adjustments in one aspect of morphology affect a number of other aspects, each with important consequences for the subsequent use and later interpretation of stone artefact function.

The ability for this research to produce results which contradict current approaches to the interpretation of stone artefact function indicates that many of the processes and mechanisms acting upon prehistoric stone artefact manufacture and use have been misunderstood. These misconceptions highlight inadequacies in previous investigations of stone artefact function, emphasise the value of adopting more rigorous theoretical and methodological approaches to the analysis and interpretation of stone artefacts and highlight the need for archaeologists to embrace a more dynamic view of the relationship between stone artefact manufacture and use.
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CHAPTER 1

UNDERSTANDING STONE ARTEFACT FUNCTION

INTRODUCTION

Archaeologists have long been concerned with the identification and interpretation of stone artefacts and the roles they may have fulfilled in prehistoric hunter-gatherer subsistence. The capacity of stone artefacts to enhance survival by increasing the past human ability to negotiate environmental and situational circumstances means that the nature of artefact use had important consequences for hunter-gather survival and overall fitness. This thesis examines and challenges current approaches to investigating stone artefact function and the underlying assumptions about human behaviour upon which they are based. Through controlled experimentation, this thesis identifies alternative ways of thinking about artefact use that have, to date, been largely neglected. In particular it focuses upon understanding the relationship between artefact morphology and function by explaining how an artefacts morphological properties impact upon its ability to perform particular tasks and on recognising the effect that changing morphology has on performance. The purpose of this thesis is to increase the accuracy of interpretations of stone artefact functions and the construction of broad level behavioural theories of the past that rely upon an understanding of artefact function.

THE IDENTIFICATION, INTERPRETATION AND EXPLANATION OF ARTEFACT FUNCTION

The earliest scientific attempts at identifying artefact functions began with the construction of artefact typologies which used the notion of 'type' as the principal analytical unit (Trigger 1989). The use of typology in the interpretation of stone artefacts has been the focus of much discussion (e.g. Dunnell 1971, 1986; Clark 1972; Hill and Evans 1972; Jelinek 1976; Gallus 1977; Thomas 1981; Cowgill 1982; Read 1982; Spaulding 1982; Whallon 1982; Dibble 1985, 1995; Beck and Jones 1989; Adams and Adams 1991; Cross 1999; Bisson 2000; Hiscock in press). It is therefore unnecessary to rehash these arguments here, other than to outline the general concepts upon which typology is based and to emphasise its role as a long standing method of examining the nature of artefact function.
Typological classifications were originally adopted in artefact analysis as a means of systematising artefact description and of understanding similarities in implement morphology. They fulfilled a descriptive rather than an interpretive role in artefact analysis. However, by the mid-twentieth century, morphologically defined types were seen to be culturally and historically 'real', imbued with social meaning that simply needed to be 'discovered,' causing artefact description to become conflated with interpretation. Similarities and differences between assemblages, based on the presence or absence of identified 'types,' were interpreted within a culture-historical framework, and seen to indicate spatial or temporal difference between the cultures that produced them (e.g. Ritchie 1961; Bordes 1969; Thomas 1981; Hill and Evans 1972; Brown 1982; see also Flenniken and Wilke 1989; Bamforth 1991a; Cross 1999). However, where inter-assemblage variation was noted in assemblages thought to have been produced by the same cultural group and to encompass a similar temporal span, morphological variation was instead explained as a product of functional difference (e.g. Posnansky 1959; Clark 1959, 1967; Kleindienst 1961; Binford and Binford 1966, 1969; Freeman 1966; Mason 1967; S.R. Binford 1968; Coles and Higgs 1969; L.R. Binford 1972). The explicit belief that the 'types' identified by archaeologists represented the intended forms of the knapper by conforming to a 'mental template' (e.g. Ritchie 1961; Cowgill 1967; Chang 1967; Gallus 1968, 1977; Thomas 1981; Mellars 1989; Hester 1993), implied that all members of a particular 'type' were the same and could therefore be given the same interpretation. Likewise, the belief that each form had been specifically designed by the knapper implied that their manufacture was to fulfill a specific purpose. Where behavioural correlates were available for observation in the form of tool-using indigenous groups (particularly in Australia), direct correlations were made between artefact form and function, with functional ascriptions based upon direct analogy with ethnographic observations (e.g. McCarthy et al. 1946; Bordes 1969; Tindale 1968; Mulvaney 1977).

A fundamental assumption of typological classification was that discrete artefact 'types' successfully performed the task for which they were intended; therefore implying different tasks were performed by different morphologies (e.g. Mitchell 1949; Clark 1959, 1967; Posnansky 1959; Kleindienst 1961; Mason 1967; Gallus 1971, 1977; Binford 1972; Sackett 1977; Dickson 1976; Brown 1982; Read 1982). The assumption that artefact form was tied to function is typified by the ascription of type labels such as 'scraper,' 'saw' and 'points' which imply specific functions (e.g. McCarthy et al. 1946; Spaulding 1953; Bordes 1961; Ritchie 1961; Gallus 1971, 1977). Retouch, its presence or absence at a given location, was
also regarded as one of the more common reflections of prehistoric intent and function (e.g. McCarthy et al. 1946; Spaulding 1953; Bordes 1961; Ritchie 1961; Gallus 1971, 1977).

In recent times, the use of typology has become less explicit in the archaeological literature. Nevertheless typological notions remain deeply embedded in archaeological interpretations and represent the most long lasting and pervasive framework for thinking about artefact function (e.g. Dumont 1987; Neumann 1988; Shea 1993; Crombe et al. 2001). While typological classifications sought to identify the functions of stone artefacts from their morphology, alternative investigations into artefact function were developing and continue to develop in parallel, based on the work of Semenov (1964) who sought to identify artefact function by characterizing the macroscopic wear patterns generated on a tool edge through use.

Since its inception by Semenov in 1964, use-wear and, later, microwear analyses became established as one of the most common methods for identifying stone artefact functions. Research revealed that the process of artefact use resulted in the development of macroscopic and microscopic wear along the working portion of the edge. As such, analysts have replicated a wide range of actions on multiple contact materials (i.e. bone, antler, wood) thought to be relevant to prehistoric hunter-gatherer survival (e.g. Semenov 1964; Tringham et al. 1974; Keeley 1975; Hartmann 1980; Vaughan 1985; Kamminga 1982; Moss 1983a; Walker 1983; Bettison 1985; Bienenfield 1985; Fullagar 1986; Grace et al. 1987; Aldenderfer 1990; Hayden 1990; Shea 1992; Shultz 1992; McDevitt 1994; Lindner and Folb 1998; Skakun 1999). These experiments are argued to have enabled the characterisation of use-wear types which include edge scarring/damage, polish, striations and rounding and the connection of these types to function. Wear types are argued to appear in differing magnitudes, orientations and locations relative to the materials worked and actions involved, such that the type of patterning produced through use may be considered distinctive of the function responsible for its development (see Semenov 1964; Keeley 1975; 1980; Odell 1975; Vaughan 1981, 1985, 1987; Hayden 1979b, 1990; Odell and Odell-Vereecken 1980; Sussman 1985, 1988; Grimaldi and Lemorini 1992; van den Dries and van Gijn 1997). Having observed the formation of wear patterning under laboratory or otherwise controlled circumstances, analysts draw analogies with the patterns of use they identify on archaeological samples in order to assign functions to prehistoric stone artefacts.
However, criticisms and problems associated with distinguishing between different types of wear have raised questions regarding the extent to which particular wear features may be regarded as being distinctive of action and contact material (e.g. Gendel and Pirnay 1982; Unrath et al. 1986; Newcomer et al. 1986; Grace 1989; Bamforth et al. 1990; Young and Bamforth 1990). The inconsistent development of striations with use (e.g. Tringham et al. 1974; Odell 1975; Corruccini 1985; Levi Sala 1988; Shultz 1992), ability of post-depositional processes and other non-use related mechanisms to produce edge scarring (e.g. Tringham et al. 1974; Keeley 1975; Rottlander 1975; Keeley 1980; Holmes 1987; Gifford-Gonzales et al. 1985; van Gijn 1990; Knutsson et al. 1988; Pryor 1988; Shea and Klenck 1993; McBrearty et al. 1998), inconsistent development of scar patterning with use (e.g. Keeley 1975; Cahen et al. 1979; Moss 1983a, b; Fullagar 1984; Bienvenfield 1985; Dumont 1987; Levi Sala 1986b, 1988; McDevitt 1994) and observations that overlaps exist between the appearances of polishes generated by different materials (e.g. Vaughan 1981; Unger-Hamilton 1984; Grace et al. 1985, 1988; Driskell 1986; Fullagar 1986; Levi Sala 1986a, 1988; Newcomber et al. 1986, 1987; Knutsson et al. 1988; Holmes 1987; Odell 1975; van Gijn 1990; Shea 1992; van den Dries and van Gijn 1992) has led many to question the ability of various wear patterns to identify artefact functions (e.g. Gendel and Pirnay 1982; Newcomer et al. 1986; Grace 1988). However, while analysts have sought to clarify these issues by identifying problems in experimental processes (e.g. Bienvenfield 1985; Newcomer et al. 1986; Knutsson et al. 1988; van Gijn 1990; Moss 1997; Gonzalez-Urquijo and Ibanez-Estevez 2003) and exploring in greater detail the processes of polish formation (e.g. Witthoft 1967; Diamond 1979; Kamminga 1979; Anderson 1980; Unger-Hamilton 1984; Fullagar 1986), the confusion surrounding the accuracy of wear to identify function, raises questions about the robusticity of the principles of use and microwear analyses.

Archaeologists have nevertheless continued to use interpretations of use-wear patterning to infer site functions and the location of specific activity areas (e.g. Lewenstein 1981; Aldenderfer 1990; Knutssson 1990; Caneva et al. 1996; Shen 2000; Fullagar and Jones 2004). Differences in site functions have been argued to be evidenced by variations in the morphological and functional composition of assemblages. Sites that exhibit a wide range of functional (and therefore morphological) diversity have been considered to represent 'base camps' (e.g. Bienvenfield 1985; Aldenderfer 2000; Shen 2000; Hogberg 2004), where hunter-gatherers regrouped in order to perform the wide range of subsistence tasks necessary for survival (Binford 1979). By comparison, those sites that show minimal morphological, and therefore functional, variation have tended to be viewed as 'activity
Understanding Stone Artefact Function

Chapter 1

specific' sites (e.g. Conkey 1980; Binford 1983; Aldenderfer 2000) in which a small group of individuals are attributed with performing a small number or, in some cases, a single task (Binford 1979). Different activity areas within individual sites have also been implied (e.g. Lewenstein 1981; Knutsson 1990; Caneva et al. 1996; Shen 2000; Fullagar and Jones 2004) and broad scale comparisons made between sites on the basis of spatial and temporal variations in the functional composition of assemblages (e.g. Keeley 1975; Cahen et al. 1979; Moss 1983a; Vaughan 1985; Kazarjian 1990). Some wear analysts have also attempted to quantify the amount of use edges are capable of withstanding in various functions before requiring retouch (e.g. Bienenfield 1985; Korobkova 1981, 1999; Richter 1996; Skakun 1999). However, implicit in each of these arguments is the assumption that the artefacts used to complete a particular task were chosen for their superior ability to perform that task. Yet wear analysts have made no attempt to explain correlations between function and morphology in terms of performance. Knowledge of the suitability of these artefacts for the functions ascribed to them and the specific features that lend it to a particular task is entirely absent. The possibility that particular morphologies may be more, or less, productive in certain tasks than are others or may perform equally well but incur different functional advantages on tool users, remains untested. This current inability to explain why a particular morphology is suited to a given function necessarily begs the question "have wear analysts explored all of the key issues necessary for the understanding of artefact function?"

Another approach to understanding artefact function has developed over the last 20 years with the creation of a series of synthetic concepts emphasising interrelationships between artefact manufacture and use within broad behavioural systems. In this approach technology is seen to contribute to, and be influenced by, a wide range of behaviours and circumstances, related to environmental adaptations and settlement patterns including variation in foraging practices (e.g. Kuhn 1994), time allocation and scheduling (e.g. Jeske 1989; Torrence 1983, 1989a,b; Bright 2002; Ugan et al. 2003), patterns of mobility (e.g. Kelly 1983, 1992; Kelly and Todd 1988; Kuhn 1991, 1994; Andrews 1994; Ingbars 1994; Hiscock 1996a; Milliken 1998; Brantingham et al. 2000) and risk (e.g. Torrence 1989b; Bousman 1993; Shea 2003; Hiscock 1994a, 2002; Ugan et al. 2003) associated with uncertainty of resource availability (e.g. Hiscock 1984, 1996a; Bamforth 1985, 1986; Jeske 1989; Jochim 1989; Lurie 1989; Kuhn 1991; Andrews 1994; Ingbars 1994; Holdaway et al. 1996; Milliken 1998; Ricklis and Cox 1993; Brantingham et al. 2000). In these models, shifts in various aspects of subsistence behaviour are argued to be ‘managed’ through technology by adopting strategies referred to as ‘provisioning systems’ (Kuhn 1995a) or the
’organisation of technology’ (Kelly 1988; Nelson 1991), that enhance various aspects of artefact performance. These strategies are argued to maximise efficiency in subsistence, both by reducing the costs, or increasing the benefits associated with tool use and subsistence artefacts. Where environments were unfamiliar and resources unreliable, artefacts could be manufactured to be multifunctional, facilitating the exploitation of a wide range of resources (e.g. Bleed 1986; Kelly 1988; Kelly and Todd 1988; Hiscock 1994b).

Likewise, constraints on time or energy could be minimised by the manufacture of specialised artefacts that enhanced the speed with which resources could be procured (e.g. Torrence 1983, 1989b; Jeske 1989; Bousman 1993) or reduced the risk of failing to procure crucial resources (e.g. Torrence 1989a; Myers 1989; Hiscock 1994a; Bleed 1996; Bamforth and Bleed 1997; Fitzhugh 2001). For highly mobile groups the adoption of either a range of small specialised tools (e.g Kuhn 1994) or larger, multifunctional tools could function to relieve transport costs associated with moving stone raw material around the landscape (e.g Andrefsky 1986, 1994; Odell and Cowan 1986; Parry and Kelly 1987; Kelly 1988; Kelly and Todd 1988; Nelson 1991; Hiscock 1994; Cowan 1999; Bamforth and Becker 2000). These concepts characterise the functional life of stone tools by drawing on cost/benefit models of economic efficiency to explain the use of certain tools or morphologies in particular circumstances.

In any given situation, the hunter-gatherer is expected to implement the technological strategy best able to minimise cost and maximise benefit. However, the dependence of these models on a number of currently untested assumptions of artefact performance is problematic. First, an inherent assumption is that hunter-gatherers always had access to the right tool at the right time regardless of circumstance which implies that all used tools attained high performance levels. The second assumption is that changes in artefact morphology are accompanied by, or reflect, improvements in the performance levels of the artefact. It is therefore implicitly assumed that all changes to artefact edges are progressive and improve performance, rather than creating a tool that attains similar or lower performance levels by selecting to enhance some qualities at the expense others. A further implication is that any number of changes to artefact morphology may be made without compromising their capacity to achieve the maximum performance levels in the specific tasks required of them. A third assumption is that the different technological strategies explored each present unique morphological signatures which enables them to be recognised in an archaeological context. At present, each of these assumptions about stone artefact performance is yet to be tested, despite the dependence of models of the organisation of technology upon their validity. As such, the extent to which organisation
of technology models currently contribute to the accurate understanding of artefact function may be questionable.

Current knowledge of stone artefact performance often derives from casual statements made by microwear analysts during use experimentation (e.g. Keller 1966; Kamminga 1982; Moss 1983a, b, 1986a, b; Vaughan 1985) as well as a handful of studies which specifically target tool performance. Wear analysts have noted a number of morphological and use variables which they consider contribute to artefact performance. These include raw material (Semenov 1964; Straus 1980; Kamminga 1982; Moss 1983a; Olausson 1983; Patterson 1981; Sussman 1985, 1988; Vaughan 1985; Fullagar 1986; Knutsson and Taffinder 1986; van Gijn 1990; Hurcombe 1992), heat treatment of raw material (Olausson 1983), edge shape in both plan and profile (Moss 1983a, 1983b, 1997; Van Gijn 1990), and edge angle (Keller 1966; Tringham, et al. 1974; Keeley 1980; Kamminga 1982; Moss 1983a; Patterson 1981; Vaughan 1985; van Gijn 1990). Variations in these traits are argued to affect the resistance of working edges to edge damage, which has been argued to adversely affect the performance of working edges by inducing more frequent resharpening and replacement (Moss 1983a; Olausson 1983; van Gijn 1990). However, while attempts have been made at control in such studies, experimentation has typically been focused on the speed and development of wear and not on the effectiveness of the edges themselves.

Studies specifically targeting artefact performance are also limited, both in number and scope, with a tendency to focus upon the effects of single variables only. Research by Keller (1966) explored the effects of edge damage on flaked edges and revealed that certain modes of use are more efficient than others. Similarly, explorations of the effect of raw material on tool performance revealed marked variation in resistance to edge attrition with varying properties in raw material (Greiser and Sheets 1979). Variations in the effect of morphology on performance have been explored (Bleed and Bleed 1987). Whilst experimentation focused on the performance of modern saws, rather than archaeological artefacts, the results demonstrated that only very slight morphological differences in the tool may be required to create dramatic differences in performance (Bleed and Bleed 1987). The one class of artefact on which multiple performance studies have been undertaken is edge-ground stone axes. Commonly, these studies compare the effectiveness of stone versus steel axes in tree felling (Townsend 1969; Saraydar and Shimada 1971; Coles 1979) or measuring the ease and time required to fell individual trees or entire forests using stone axes (e.g. Iverson 1956; Carneiro 1979; Coutts 1979). In each of these studies, performance was measured by the length of time required to fell a certain number or type
of tree. However, the levels of control over relevant variables exercised in these experimental programs are generally quite poor (with the exception of Mathieu and Meyer 1997).

While limited in the range of motor actions and tools examined, these studies identify a number of important variables with broad implications for understanding performance relative to a wide range of artefacts. However the rarity of experiments conducted means that experimental data and analyses on artefact performance are distinctly lacking. Morphological variables specific to stone artefacts such as edge shape, edge angle, contact angle, and any possible interactions between them, have never been investigated.

The lack of knowledge regarding this aspect of artefact function and the widespread dependence of current approaches to artefact function upon assumptions of artefact performance, means it is necessary to ask, “how well would current approaches stand up to independent testing?” Further, the importance of being able to understand and identify differences in artefact performance levels in an archaeological context means intensive investigations into artefact performance are a necessity for future research and leads us to ask “how should investigations into artefact performance proceed?”

It is clear from the previous discussion that current approaches to the interpretation of stone artefact functions are dependent upon a number of assumptions about artefact performance that have not been tested. The extent to which current approaches may be regarded as reliable indicators of stone artefact function is therefore dependent upon understanding artefact performance and testing relevant assumptions. The ways in which this thesis begins to address these problems is detailed below.

**THESIS AIMS**

This thesis seeks to address the following problems: *How do we determine the functions of stone artefacts? And how well do stone artefacts perform the tasks required of them?*

In answering these questions it is necessary to first ask a number of more specific questions relevant to the current approaches advocated for investigating stone artefact function. This enables the identification of gaps in current knowledge, areas in need of additional research and important principles that are able to be built upon in order to better understand stone artefact function and its role in broader behavioural systems.
1. How robust are the principles of use-wear/microwear analyses?

Wear analyses have been the focus of much debate due to widespread confusion regarding the extent to which wear patterns can be regarded as distinctive of specific types of use. Problems surround the interpretation of each type of wear used to identify artefact function including striations, edge damage and polish. Analysts themselves point to insufficient use of the artefact, differences between experimental programs and the effects of additional variables as the source of much of this confusion. However, the existence of contradictory evidence invariably implies that the principles of use-wear analyses may not have been adequately tested. The principles of wear analyses and the experimental programs responsible for their development are discussed in Chapter 2 in order to determine the interpretive strength of functional ascriptions of stone artefacts based on wear analyses.

2. Have wear analysts explored all of the key issues necessary for understanding artefact function?(269,500),(934,905)

The specific focus of wear analysts has been stated as the attempts ‘to see if artefacts which have the same shape are all used for the same task and to discover what that task was’ (Hurcombe 1992:79). Establishing direct one to one correlations between form and function has been the basic goal. As a consequence experimental programs into artefact function tend to be restricted to repetitive use of stone edges in specific actions in order to generate distinctive types of wear (e.g. Semenov 1964; Keeley 1975; Kamminga 1982; Hayden 1990; Korobkova 1999) and calculate amounts of material worked/removed (e.g. Skakun 1999). The construction of site/assembly interpretations from the identification of individual artefact functions are discussed in Chapter 3, and reveal performance as a crucial area of artefact function that has absent from previous investigations of stone artefacts. Implicit in these interpretations is the assumption that artefacts were well suited to performing the tasks to which they were applied. Yet variations in the performance levels of different artefacts and the features which contribute to performance success have been almost entirely ignored in the use-wear literature. As a consequence, wear analysts claim to be able to identify which tools were used to perform particular functions, but are unable to explain why a tool lends itself to a given function or how well it is able to perform the task.
3. How well do models of the organisation of technology contribute to an understanding of artefact function?

Models based on the organisation of technology or provisioning systems view artefact functions in a broader sense than that proposed by wear analysts. In addition to performing activities such as cutting or scraping, artefacts are seen to function as a crucial means by which hunter-gatherers could enhance the speed and efficiency of important subsistence activities. Circumstances in which time or energy are constrained, risk of resource procurement failure is high or constraints exist on the transport of raw materials are each predicted to be managed by adjustments to technological provisioning systems. Central to these models is the belief that hunter-gatherers will always have access to the right tool for any function and at the right time. They therefore operate under two basic assumptions: that artefacts will consistently function well irrespective of how much change the edge incurs to accommodate requirements such as multifunctionality, and that the best performing morphologies for each function can be identified in artefact assemblages. Current models of the organisation of technology and their relative merits are the focus of chapter four. However, we can briefly demonstrate these problems here using the mobility strategies example mentioned above.

In order to reduce transport costs hunter-gatherers are argued to carry either a number of small specialised tools (e.g. Torrence 1989) or fewer larger more multifunctional tools (e.g. Kuhn 1994). The first argument assumes that size does not contribute substantially to artefact function, allowing artefact sizes to be reduced to accommodate transport requirements without adversely affecting the artefact’s ability to perform its intended task. The second assumes that multifunctional tools exist and that any compromises in performance that may occur from utilising the one tool for many tasks will not be sufficient to make the tool less functionally valuable. However in order to test these models, archaeologists must understand the relationship between stone artefact morphology and performance. The capacity for a tool to be multifunctional and/or reshaped to suit mobility requirements is necessarily dependent upon which specific features of the artefact contribute to its performance. If archaeologists are going to discuss artefact function in this way it is first necessary to know how well artefacts perform, how they function, when they will be best used and how to identify them in the archaeological record. At present, archaeologists lack this understanding due to the lack of previous experimentation into this aspect of artefact function, making it virtually impossible to identify high performing forms and their associated functions in an archaeological context.
Models of organisation of technology therefore accompany wear analyses in being predicated upon assumptions of artefact functionality that are, to date, untested.

4. How should investigations into artefact function proceed?

The previous discussions demonstrate that the current literature fails to grapple adequately with the problem of identifying and interpreting the functions of stone artefacts. Two important problems with current approaches are revealed in the literature. The first is that present concepts of artefact function may not stand up to rigorous independent testing. Existing confusion surrounding the identification and interpretation of wear may be a product of poor experimental protocols and failure to identify important variables contributing to wear development. Likewise, the dependence of models of the organisation of technology upon untested assumptions of artefact function may mean that notions of artefact effectiveness and their implications for artefact functionality may change with greater knowledge of artefact performance. The second is the lack of a coherent conceptual framework within which to explore artefact function. This is evidenced by the dearth of previous investigations into artefact performance. Chapter five fills this void in methodology by exploring appropriate ways in which to study artefact performance and effectiveness. Additional insight is drawn from ceramics analysts and a methodological framework appropriate to understanding stone artefact performance is forwarded. This framework is used to guide experimentation and a program designed to both independently test current approaches as well as provide much needed new data on artefact performance is constructed in chapter six.

The failure of more traditional approaches to explain basic notions of artefact use and performance highlights the need for a different experimental approach. The program outlined in chapter six advocates experimentation under highly controlled circumstances. This allows results to be quantified and subject to systematic repetition, as well as enabling the specific roles of different use and morphological variables to be understood. By mechanizing the tool use actions tested all relevant variables are able to be controlled allowing interactions between variables to be systematically monitored and analysed. The value of the methodological approach and controlled experimentation of artefact functionality carried out in this thesis is threefold:

1. It enables rigorous testing of the robusticity of current approaches and thus their interpretive value to broader questions of hunter-gatherer subsistence,
2. It offers a new way of investigating ideas of functionality and tool use that avoids the assumptions of previous approaches, and

3. It facilitates an understanding of interactions between useability/functionality and tool form, which represents the primary means of differentiating tools and functions from one another.

5. What are the important morphological and use variables affecting artefact function?

The isolation of individual variables contributing to artefact performance made possible by the experimental program detailed in chapter six enables the identification of those variables have a statistically significant effect on artefact performance and those that do not, relative to each tool function tested. It is also possible to determine exactly what is required for an edge to perform successfully and how much morphological variation is feasible before artefact function becomes compromised. These results are discussed in chapter seven. The ability for specific variables to prolong the number of strokes for which an edge remains productive or to enhance the short term performance of the edge can also be explored; the results of which are detailed in chapters eight, nine and ten.

CONCLUSIONS

In order to meet the goals outlined for this thesis, discussion will proceed with an examination of each of the three interrelated aspects of tool function and functionality discussed above; wear analyses, organisation of technology/provisioning systems and the assumptions about tool performance upon which they are dependent. Supplementing the minimal research previously conducted into stone artefact performance is a new and innovative approach to experimentation which is outlined and conducted in relation to the use of unretouched edges of flaked stone artefacts. The data developed and discussed in this thesis aims to contribute to the understanding, interpretation and identification of artefact function in archaeological assemblages and therefore to our ability to construct accurate interpretations of the past. An examination of the identification and ascription of tool function through wear analyses is the focus of the following chapter and begins this investigation into artefact function.
INTRODUCTION

This chapter examines the principles under which wear analyses operate. The widespread use of wear analyses to ascribe functions to stone artefacts and the subsequent use of this data to construct site and regional interpretations of tool use implies that analysts are confident of their ability to identify and interpret wear data accurately. Wear analyses are prolific in the archaeological literature and continue to be one of the most common approaches for the determination of artefact function currently available. However, examination of the microwear literature reveals that faith in the current ability of wear analyses to interpret artefact function has been misplaced. Problems with the distinctiveness of polish and edge-scarring as wear types indicative of artefact function have long been recognised in the use-wear literature throughout the world (for polish examples see Vaughan 1981; Unger-Hamilton 1984; Grace et al. 1985; Driskell 1986; Levi-Sala 1986, 1988; Newcomer et al. 1986; Holmes 1987; Odell 1990; Shen 2000; for edge-scarring examples see Keeley 1975; Moss 1983a; 1986a; Bienenfield 1985; Fullagar 1984, 1986; Sussman 1985, 1988 Dumont 1987). While attempts have been made to resolve some of these issues, in general analysts have agreed to draw on all available wear types in an attempt to circumvent problems specific to one or other type. However, the following discussion identifies multiple problems in the development of current perceptions, which includes inadequate experimental control of the variables deemed critical to the development of use-wear and a widespread failure to systematically test each variable. As a consequence, analysts have potentially failed to identify some of the most important variables likely to affect wear and are currently unable to adequately quantify the effects of specific variables upon wear development. These discoveries may have serious implications for the validity of the most fundamental principle in use-wear analyses; that variations in artefact function are uniquely reflected in the combinations and patterns of wear produced by that use. The widespread failure of wear analysts to identify interpretive difficulties at an experimental level has meant that several generations of wear analysts have investigated wear using the same problematic approaches, reinforcing the mistakes of previous generations of wear analysts and contributing to the misconceptions which
characterize the current use of wear analyses to ascribe functions to prehistoric stone artefacts.

**THE DEVELOPMENT OF WEAR ANALYSES**

Prior to and continuing on in conjunction with, the discovery of wear analyses, interpretations of the functions of stone artefacts occurred within a formalised typological framework. The belief that formalised types were manufactured to a specific prehistoric design and to fulfil a specific purpose enabled early typologists to group artefacts of similar morphology together and ascribe them the same intended function (e.g. Roth 1904; McCarthy et al. 1946; Spaulding 1953; Ritchie 1961; Tindale 1968; Gallus 1971, 1977 see also Dunnell 1986). Recurring tool types were easily recognised and where ethnographic parallels existed, it meant identification of artefact function required only a visual assessment of the archaeological material. It was expected that prehistoric tools would have performed a similar range of functions as those required of modern tools and artefacts were thought to function in much the same way as their modern equivalents (e.g. McCarthy et al. 1946; Ritchie 1961; Tindale 1968; Bordes 1969). Comments by Bordes (1969:3) illustrate this approach: ‘a backed blade (or a blade with a blunted edge) resembles a penknife blade that one can deduce the function ‘knife,’ likening the unretouched edge to a cutting edge and the edge blunted by steep retouch to the back.’ However, in the 1960s and onwards, researchers of technology identified alternative explanations for artefact form. These included the role of differing properties of the raw materials used (e.g. Tringham 1971; Hill and Evans 1972; Jelinek 1976; Sackett 1977), stylistic difference (e.g. Jelinek 1976; Sackett 1977; Brown 1982; Read 1982) maintenance and rejuvenation activities (Frison 1968; Mellars 1970; Jelinek 1976) adaptive behaviour and changes in circumstances (e.g. Mellars 1970; Binford 1972) and differences in mobility patterning (e.g. Binford 1979, 1980). These studies represent early examples of the functional interpretation of different tool types within broader based models of hunter-gatherer subsistence strategies. More recent approaches are discussed in detail in chapter 4.

In 1964 (translated to English in 1968) Semenov’s published his seminal use-wear study entitled *Prehistoric Technology* which marks the beginning of use-wear analyses in their present form. Using low-level magnifications of up to 60X, Semenov (1968) identified patterns in the orientation and distribution of striations, abrasion and scarring wear types on the edges of stone tools. These were argued to be indicative both of the motion in which the artefact was used and the relative hardness of the material worked. Semenov (1968) saw the identification of artefact functions through use-wear as a means of challenging typological
assumptions about the relationship between artefact form and function by providing an independent evaluation of these ideas.

Semenov identified four different types of wear: striations, abrasions, edgescarring/fractures and polish. These four wear types remain the primary indicators of use-wear and much research has been devoted to better understanding each of them by subsequent wear analysts. Representing minute scratches, lines or grooves, striations are inferred to result from contact between the tool edge and contact material under pressure and to occur when the worked material is harder than, or as hard as, the tool's raw material (Keeley 1980; Tringham et al. 1974; Brink 1978; Odell and Odell-Vereecken 1980; Mansur 1982; Kamminga 1982; Corruncini 1985; Knutsson 1986; McDevitt 1994). Abrasions or abrasive wear are caused by the contact of free and fixed particles with the surface of the tool (Keeley 1980; Hurcombe 1992). Edge-scarring is argued to be the product of the forces applied during use between the functioning edge and the contact material being worked. The greater the force applied during use the larger the scars that are expected to develop. Use fractures are described in terms of their orientation, initiation type (bending, hertzian or snap), size and termination type (step, feather, hinge or snap). Different combinations of each of these features are argued to indicate the hardness of the material worked at the type of motion involved (Tringham et al. 1974; Tomenchuck 1979, 1988a; Odell 1980; Odell and Odell-Vereecken 1980; Lewenstein 1981; Bienenfeld 1985; Salls 1985; Cotterell and Kamminga 1986; Knutsson 1986; Akoshima 1987; Shultz 1992; Shea and Klenck 1993; Lindner and Folb 1998; Tomenchuck and Stork 1998). A great number of investigations have been undertaken into the formation, characterisation and interpretation of use polishes (Witthoft 1967; Crabtree 1974; Del Bene and Shelley 1979; Del Bene 1979; Diamond 1979; Hayden and Kamminga 1979; Anderson 1980; Anderson-Gerfaud 1981, 1983; Masson et al. 1981; Meeks et al. 1982; Kamminga 1979, 1982; Moss 1983a; Mansur-Franchomme 1983; Unger-Hamilton 1984; Bettison 1985; Vaughan 1985; Fullagar 1986; van Gijn 1990; Hurcombe 1992) and yet these aspects are still poorly understood. Whether the product of abrasion, translocation or surface melting, by definition ‘use-polish’ generally refers to an altered surface which reflects relatively more light. The term ‘polish’ is always relative to the unused edge or surface in question (Fullagar 1986:122).

While all analysts acknowledge the existence of each of these forms of wear, they differ in the interpretive value they place on each and the extent to which they may be regarded distinctive of mode of action and contact material. Semenov (1968) placed greatest
interpretive value on striations and abrasions as reliable indicators use, however subsequent investigations suggest that striations are considerably less common than Semenov suggested (e.g. Tringham et al. 1974; Odell 1975; Moss 1983a; Corrucini 1985; Levi Sala 1988; Shultz 1992; van den Dries and van Gijn 1997), and may be regarded as indicative of motion of use only (Odell 1975; Kamminga 1982; Moss 1983a; Bienenfeld 1985; van Gijn 1990; Shea 1992; Linder and Folb 1998 but see Hay 1977; Fedje 1979; McDevitt 1994 for exceptions). As such, the stream of analysts immediately inspired by Semenov placed greater emphasis on the nature and number of edge scars created through use and the location and distribution of macroscopically visible polishes (e.g. Bordes 1971; Hayden and Kamminga 1973; Tringham et al. 1974; Kamminga 1977, 1982; Brink 1978; Odell 1977, 1979b; and Odell-Vereecken 1980).

Early observations of polish were made under low magnifications (up to 60x), under which the location and distribution of polish could be determined but not the specific contact material (e.g. Semenov 1968; Bordes 1971; Hayden and Kamminga 1973a; Ranere 1975; Kamminga 1977, 1982; Odell 1977, 1979b; Brink 1978). However, in the mid to late 1970s Keeley (1975, 1980) argued that, at high magnification, (up to 200x) different types of polish were distinguishable, each distinctive of the material worked. Characteristic features in polishes were argued to be visible which allowed the identification of categories of contact-material such as meat, wood, bone, hide and so on (Keeley 1975, 1980). Following publication of the results of an extremely successful blind test of the ability of polish type to differentiate between contact materials (Keeley and Newcomer 1977), there developed a generation of polish analysts who sought to better understand and characterise the phenomenon of polish, combining the identification of polish characteristics with broader functional analyses (e.g. Cahen et al. 1979; Anderson-Gerfaud 1981; Dumont 1982; Moss 1983a; 1986a; Sussman 1985, 1988; Fullagar 1986; Knutsson 1986; Levi Sala 1986a, 1988; Knutsson et al. 1988). However, increasing numbers of investigations into wear analyses corresponded with increasing numbers of reports of contradictory and inconsistent evidence, causing analysts to question the reliability of both polish and scarring as indicators of artefact function.

A series of blind tests exploring the distinctiveness of individual polishes produced poor results (e.g. Newcomer and Keeley 1979; Odell and Odell-Vereecken 1980; Holley and Del Bene 1981; Gendel and Pirnay 1982; McGuire et al. 1982; Newcomer et al. 1986; Unrath et al. 1986; Bamforth et al. 1990; Young and Bamforth 1990 but see comments by Keeley 1981; Odell 1985; Fullagar 1986; Moss 1987a; Hurcombe 1988; van Gijn 1990) and led
The Principles of Wear Analysis

Chapter 2

some to conclude that polishes were poorly correlated with contact materials (e.g. Odell 1981, 1985a; Stafford and Stafford 1983; Shea 1988). Efforts to establish a means of differentiating polishes that was quantitative, rather than qualitatively derived, also proved futile with a series of computerised texture analyses undertaken (e.g. Grace et al. 1985, 1987; Grace 1989). Using two-dimensional image processing techniques to analyse the tone and texture of different micropolishes, Grace and colleagues concluded that polishes could not be differentiated on the basis of texture and, therefore, nor could the contact materials responsible for generating them (but see also objections by Moss 1987a and reply Newcomer et al. 1988 and Knuttsson et al. 1988). These results, coupled with similar qualitative observations by many analysts (e.g. Odell 1975; Vaughan 1981; Unger-Hamilton 1984; Levi Sala 1986b, 1988), increased mistrust in polish as a distinctive indicator of function. Overlap in the appearance of polishes was cited as the primary problem, with many polishes argued to bear characteristics that were too similar to allow them to be differentiated (e.g. Vaughan 1981; Unger-Hamilton 1984; Grace et al. 1985, 1988; Driskell 1986; Fullagar 1986; Levi-Sala 1986b, 1988; Newcomer et al. 1986; Holmes 1987; Knuttsson et al. 1988; Odell 1981, 1990; van Gijn 1990; Shea 1992; van den Dries and van Gijn 1997; Shen 2000; Skriver 2004). Overlaps have been specifically noted between the polishes produced by wood and antler polish (Keeley 1975; Knuttsson et al. 1988), bone (Unrath et al. 1986) and sometimes hide (Unrath et al. 1986; Skriver 2004). Most analysts acknowledge that the basic criticism of polishes - that they are not necessarily distinctive of contact materials, not well defined and not discrete - is valid (e.g. Moss 1983a, 1997; Bienefeld 1985; van Gijn 1990a; Fullagar 1986, 1994; Shea and Klenck 1993; Grimaldi and Lemorini 1995; Kealhofer et al. 1999).

Edge-scarring was found to be equally problematic with a number of analysts observing substantial differences in the patterns of scarring produced under conditions that were thought to be identical (e.g. Keeley 1975; Vaughan 1981; Moss 1983a; Fullagar 1984, 1986; Bienefeld 1985; Dumont 1987). A high degree of variability was found to exist in flake sizes and types for each category of hardness or softness of worked material (e.g. Keeley 1980; Vaughan 1981) while others demonstrated that a consistent relationship between scar type and worked material did not exist, with only a tentative one demonstrable between scar types and use motion (e.g. Keeley 1980; Moss 1983a). In addition, the capacity for non-use related processes such as post depositional processes or retouch to mimic use-scarring meant that the use of scarring alone to determine function was questionable (e.g. Trinham et al. 1974; Keeley 1975, 1980; Rottlander 1975; Keller 1979; Vaughan 1981; Gifford-Gonzales et al. 1985; Dumont 1987; Holmes 1987; van Gijn 1987; Knuttsson et al.
1988; Pryor 1988; Beyries 1990; Shea and Klenck 1993). As a consequence, analysts vary in the importance they place on edge-scarring due to differing opinions of the interpretive value of scarring to identify function.

Two approaches to wear analyses therefore developed. The first emphasised Semenov’s (1968) low-powered magnification of edge damage, abrasion, macroscopic polish and striations; edge-scarring was considered an invaluable indicator both motion of use and hardness of the material worked (‘use-wear analysis’) (e.g. Tringham et al. 1974; Tomenchuk 1979, 1988a; Odell 1980, 1990, 2001; Siegel 1984; Salls 1985; Odell et al. 1976; Akoshima 1987; Shultz 1992; Shea and Klenck 1993; Tomenchuk and Stork 1998; Lemorini 2006; Martindale and Jurakic 2006). The second approach advocates supplementation of the low-powered approach with high-powered magnifications to identify distinctive polishes (‘microwear analysis’), calling on edge-scarring to support interpretations of other types of wear (e.g. Anderson-Gerfaud 1981; Sussman 1985, 1988; Juel Jensen 1988b; Knutsson et al. 1988; Aldenderfer 1990; McDevitt 1994; Hogberg 1996; Kay and Solecki 2000). Aware of the problems associated with both wear types, most analysts now advocate a ‘combination’ approach, drawing on all available forms of wear and acknowledging and accommodating for known problems (e.g. Hayden and Kamminga 1979; Lewenstein 1981; Moss 1983a; Bienenfield 1985; Levi-Sala 1988; Aldenderfer et al. 1989; Borrass 1990; van Gijn 1990; Fullagar 1994; Grimaldi and Lemorini 1995; Hardy 1999; Kealhofer et al. 1999; Shen 2000).

A number of attempts have been made to resolve these issues including conducting intensive studies into understanding the development (Moss 1983a; Vaughan 1985; Fullagar 1986; van Gijn 1990; Hurcombe 1992) and formation of polish (Witthoft 1967; Crabtree 1974; Del Bene and Shelley 1979; Del Bene 1979; Diamond 1979; Hayden and Kamminga 1979; Anderson 1980; Anderson-Gerfaud 1980, 1983; Masson et al. 1981; Meeks et al. 1982; Kamminga 1979, 1982; Moss 1983a; Mansur-Franchomme 1983; Unger-Hamilton 1984; Bettison 1985; Vaughan 1985; Fullagar 1986; van Gijn 1990; Hurcombe 1992), its description (Keeley 1980; Moss 1983a; Fullagar 1986; van Gijn 1990), quantification (Dumont 1982; Grace et al. 1985, 1987; Grace 1989; van Gijn 1990) differentiation using higher magnifications (e.g. Anderson 1980; Del Bene 1980; Mansur Franchomme 1983; Bettison 1985; Knutsson 1986; Sussman 1988; Alvarez et al. 2001; Stemp and Stemp 2001) and the identification of residues (e.g. Loy 1993). Likewise, studies investigating the effects of trampling (e.g. Keeley 1980; Moss 1983a; Shea and Klenck 1993; McBrearty et al. 1998), post depositional damage (e.g. Gero 1978; Levitt 1986; Holmes 1987; van Gijn 1987;
Knutsson et al. 1988), spontaneous retouch (e.g. Newcomer 1975, 1976; Martindale and Jurakic 2006) and retouch (e.g. Martindale and Jurakic 2006) on the appearance and frequency of edge-scarring have been conducted in an effort to ensure that use scarring can be differentiated from those caused by other factors. However, problems associated with the failure of scar patterning to be uniquely associated with specific functions have not been adequately addressed. Likewise, despite the use of increasingly more technical approaches for interpreting polishes, the most recent blind test conducted, focussing on the identification of tool prehension and hafting from use-wear (Rots et al. 2006), revealed ongoing problems with the association between polish and contact material. The current 'band-aid' solution of adopting a combination approach to wear analyses fails to identify the causes of noted variability in wear and may, in fact, be compounding the problem. Whilst avoiding total dependence on a single problematic wear type, advocates of the combination approach implicitly assume that by utilising as many different forms of wear as possible, any problems associated with particular wear types will be compensated for by other types present. The possibility that, rather than avoiding the problems associated with particular wear forms the use of all wear types may instead compound the problems associated with each, has not been considered. In some cases, the problems of different wear types may be complimentary and result in all wear types suggesting a similar action and contact material. In other cases, however, it is possible that the different wear types will provide conflicting evidence, with some features indicating soft wood as the contact material and others hide and so on, on the one functional edge. Conflicting evidence of the functions represented by wear patterning may be a contributing factor to the ongoing inability of wear analysts to precisely define how, and in what way, wear characteristics may be considered distinctive of action or contact material.

Over the last 25 years more than 400 articles have been published utilising or investigating the principles of use-wear (Odell 2001). Yet despite this exhaustive body of literature, conflicting evidence and discrepancies between the patterns of wear argued to be generated under known and similar conditions persist. As such, while most analysts believe that unique correlations exist between use actions/contact materials and edge wear patterning, none is able to provide an unchallenged definition of exactly which wear patterns are associated with, or expected by, which function. This inability must invariably lead us to question the reliability of functional ascriptions of artefacts on the basis of wear analyses. Two probable causes of the inability of wear analyses to differentiate function of the basis of wear are identified here. The first is that the experimental protocol upon which current theory is based and which has been carried out in a more-or-less identical fashion since
Semenov's initial publication (e.g. Semenov 1968; Tringham et al. 1974; Keeley 1975; Wyand and Bayhem 1976; Anderson 1980; Spear 1980; Lewenstein 1981; Vaughan 1981; Kamminga 1982; Mansur-Franchomme 1983; Moss 1983a; Olausson 1983; Corrucini 1985; Sussman 1985; Fullagar 1986; Akoshima 1987; Bradley and Clayton 1987; Levi Sala 1988; Aldenderfer et al. 1989; van Gijn 1990; Collins 1993; McDevitt 1994; Hardy and Garufi 1998; Linder and Folb 1998; Fullagar and Jones 2004; Martindale and Jurakic 2006), is problematic, with these problems being mimicked by subsequent analyses rather than being rectified. The second potential source of variation in wear patterning is the existence of alternative and confounding variables which previous experiments have failed to examine, the effects of which have therefore remained unquantified. The relevance and likelihood of each of these two arguments proving important sources of the observed variation between function and wear patterning is highlighted in the following discussion of current experimental protocol which illustrates the quality of the data upon which the principles of wear analyses are currently based.

EXPERIMENTAL RESEARCH

Like many experimental investigations into prehistoric behaviour, notions of the relationship between artefact function and use-wear have been derived from the generation of control samples. Multiple experiments have been undertaken in the present, under known and arguably controlled conditions, in order to generate wear on the edges of stone tools, comparable to that observed in the past (Semenov 1968; Keeley 1975; Hartmann 1980; Kamminga 1982; Bettison 1985; Bienenfield 1985; Fullagar 1986; Aldenderfer et al. 1989; McDevitt 1994). Experimental programs generally conform to one or other of two approaches: investigative or replicative. Investigative approaches follow, almost to the letter, the course established by Semenov (1964) and involve conducting experiments on a range of use related variables such as edge angle, contact material and raw material. These experimental programs are designed to familiarise the analyst with the effects of individual variables in such a way as to allow them to identify the functions responsible for the various patterns found on archaeological specimens (e.g. Tringham et al. 1974; Keeley 1980; Vaughan 1985; Kamminga 1982; Mansur-Franchomme 1983; Fullagar 1986; Tomenchuk 1988b; Akoshima 1987; Fullagar and Jones 2004). However, while many analysts follow an identical protocol, they differ in the variables recognised and tested, generating a lack of standardisation in the experimental processes and a lack of comparability in results between programs, as has been noted previously (e.g. Bienenfield 1985; Gonzalez-Urquijo and Ibanez-Estevez 2003). Replicative experiments are less
generalised and seek to explain a specific type of wear identified a particular artefact edge (e.g. Salls 1985; Shea 1992; Kamp 1995; Lindner and Folb 1988; Skakun 1999; Crombe et al. 2001). However, regardless of the purpose of experimentation, each follows a similar protocol, such that the problems identified here are relevant to the entire range of experimental programs currently responsible for the interpretation of wear analyses.

Wear analysts recognise a number of variables as influencing the development and location of wear. These include raw material, use motion, worked material, state of worked material, duration of tool use, edge angle and profile, edge section, contact aspect, pressure of use and skill of the experimenter. However, while many analysts acknowledge the likely affects of each of these variables, very few have successfully tested or controlled them experimentally. Table 1 lists the variables noted by each analyst to contribute to the development of wear, relative to those that are specifically controlled and/or tested in each experimental program. It is necessary to note here that the variables argued to have been tested by each author may differ in some cases from those marked as having been adequately tested in Table 1. This is because, in most cases, analysts have been unaware that the experimental approach used is incapable of accurately quantifying the effects of the variables they seek to test. This is due to three primary flaws characteristic of current experimental protocol:

1. Failure to control for, or hold constant, the values of those variables that are recognised to contribute to wear development, but which are not being specifically targeted in each study. In order to adequately test an individual variable and attain internal validity (Plutchik 1968; Christensen 1997) all other relevant variables need to be held constant. In the case of use-wear, this requires that values such as contact material, edge angle, duration of use, speed of use, pressure are all held constant while action alone is varied, or contact material alone is varied and so on. By allowing variation to exist in the levels of other important variables analysts have limited their ability to correlate wear patterns with a particular variable - relationships of causality are impossible to identify. The specific effects of the individual variables being tested cannot be differentiated from those created by the unquantified effects of uncontrolled variables. As such, rather than testing the effects of contact material or use motion on wear development, these experimental programs in fact test the combined effects of contact angle, edge angle, pressure, speed and so on, on the development of wear. Direct correlations between
individual variables and wear unavoidably become obscured by ‘noise’ generated by the effects of uncontrolled variables.

Table 1. Variables identified as impacting upon wear relative to those systematically investigated in experimental use-wear.

<table>
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<tr>
<th>Author(s)</th>
<th>Date</th>
<th>Manual</th>
<th>Mechanical</th>
<th>Raw Material</th>
<th>Contact Materials</th>
<th>State of Contact Material (H2O Content)</th>
<th>Use of Abrasives</th>
<th>Use Motion</th>
<th>Contact Angle</th>
<th>Contact Surface</th>
<th>Duration of Use</th>
<th>Force Applied/Pressure</th>
<th>Edge Shape - cross section</th>
<th>Edge Shape - profile/plan shape</th>
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✓ = Variable is acknowledged by the author to affect wear
☒ = Variable held constant or tested

2. Lack of experimental repetition prohibiting statistical verification of results. The general failure of wear analysts to repeat identical experiments a number of times means that the results of each experimental program tend to represent ‘one-offs.’ It is therefore unknown whether the results generated in an experimental program are truly representative of particular combinations of variables or the aberrant products of unknown interactions. Again, much of the variation noted between patterns of wear produced by different analysts but under similar circumstances, may be due to the inclusion of aberrant results in comparisons.
3. Failure to systematically test every variable thought to affect the development of wear. With the exception of edge angle, the effects of variations in edge morphology and retouch, on the appearance of wear have been entirely neglected. The unquantified effects of these variables may well have contributed to the noted discrepancies between wear produced under arguably similar conditions.

Clarification of these aspects is possible through a brief examination of the fundamental principles of experimental research. Four broad reasons are recognised for conducting experimental research: 'to determine the relations between two or more variables, ...to extend the range and study of a variable, ...to increase the reliability of reported findings, ...and to test theory' (Plutchik 1968:22-24). In all cases, 'the goal of the researcher is to attain internal validity....Internal validity refers to the extent to which we can accurately state that the independent variable produced the observed effect' (Christensen 1997:229). That is, that the observed response was caused only by the independent variable. Within an archaeological context experimentation focuses on human behaviour and its related material correlates. Due to the emphasis on understanding the relationship between cause and effect in experimental investigation, those aspects of human behaviour which can be directly related to principles of methodological uniformitarianism, or 'where the principle of actuality applies' (van Gijn 1990:24), are particularly suitable for experimental testing. The ability to replicate the manufacture and use stone artefacts under known conditions means that artefact performance and function are well suited to investigation by experimentation.

Three important criteria are generally used to judge causality in experimentation: cause and effect must be contiguous, cause must always precede effect and there must exist 'a necessary connection between a cause and its effect' (Plutchik 1968:145). Concepts of causality differentiate between necessary and sufficient conditions in which 'A necessary condition of cause for the occurrence of an event is a circumstance in whose absence the event cannot occur. A sufficient condition for the occurrence of an event is a circumstance in whose presence the event must occur' Copi (1953:328; see also Plutchik 1968; Christensen 1997). As such, inference of cause from effect will only be possible when using the necessary condition, whereas inference from cause to effect requires the sufficient condition (Copi 1953). These conditions of causality dictate that, all other things being equal, specific causes will consistently result in the same effects. Where the relationship between cause and effect is necessary, then under certain conditions a cause can only result in one possible outcome. However, fundamental to concepts of causality is their qualification by an 'all other things being equal' clause which requires the stability of all other surrounding
conditions (Copi 1953; Hempel 1966; Plutchik 1968); that is, the control of all other relevant variables. As such, experimental design is required to minimise or eliminate all potential sources of error/bias to enable unequivocal causal connections to be identified.

Experimental bias will result from failure to identify all relevant variables, inadequate sampling procedures, unsystematic/imbalance treatment of variables and unsuitable analysis of data (Plutchik 1968). A final and vital source of error is lack of experimental control; both of the variables being systematically tested and of other, potentially confounding, variables required to keep conditions constant and comparable. The variables in greatest need of being kept constant are those capable of affecting the variable being measured. Confounding results will occur 'when the experiment contains a variable that systematically varies with the independent variable' (Christensen 1997:229), making it impossible to establish how much of an experimental response is the product of the independent variable relative to extraneous and uncontrolled variables. The establishment of universal relationships of causality through experimental investigation is therefore dependent upon the use of adequate control of all relevant variables.

In combination, the three flaws in experimental protocol highlighted above mean that not only are the effects of a number of potentially important variables entirely unknown, but that our understanding of variables currently considered to be well established may be largely inaccurate. These three points are best illustrated in the use-wear literature by exploring those variables currently considered to make the greatest contribution to the development of wear and the evidence upon which these ideas are based.

IDENTIFYING AND TESTING USE-WEAR VARIABLES

Use Motion and Contact Material

The use of edge wear to identify use action and contact material necessarily implies that these two variables are the greatest source of distinctive variation in wear patterning, and other use related variables thought to contribute to a lesser extent. Four broad categories of use motion are identified in the wear literature: 1) transverse (including actions such as scraping, planing or reaping), 2) longitudinal (such as sawing, cutting, slicing), 3) vertical (such as drilling, incising or engraving), and 4) impact actions (such as chopping or adzing). Use action is argued to determine the location of wear by dictating which areas of the edge are in contact with the worked material and the direction of force involved in the use action. For example, in longitudinal actions vertical pressure is applied evenly to both
aspects of the working edge, resulting in the even distribution of wear along both aspects (e.g. Tringham et al. 1974; Dumont 1982; Akoshima 1987; Shea and Klenck 1993; Alvarez et al. 2001). By comparison, scraping activities involve the contact with only one aspect of the working edge, resulting in a predominance of wear along the contact aspect (e.g. Tringham et al. 1974; Fullagar 1986; Akoshima 1987; Hayden 1990; van Gijn 1990; Hurcombe 1992; Shea and Klenck 1993; Alvarez et al. 2003). Differences in contact material and its relative state (i.e., wet or dry) are argued to affect the intensity and appearance of wear (e.g. Hayden 1979, 1990; Odell et al. 1976; Moss 1983a; Corrucini 1985; Vaughan 1985; Fullagar 1986; Levi Sala 1988; van Gijn 1990). Hard materials such as bone or stone are thought to produce significantly greater levels of edge damage and striations than are soft materials such as plants, while soft materials are argued to result in smaller scars that are fewer in number and more invasive and gentle polish (e.g. Tringham 1971; Tringham et al. 1974; Keeley 1975; Tsirk 1979; Odell 1980, 1981; Spear 1980; Lewenstein 1981; Bienenfield 1985; van Gijn 1990; Shea 1992; Becker and Wendorf 1993; Shea and Klenck 1993; Tomenchuck 1988a; McDevitt 1994; van den Dries and van Gijn 1997; Martindale and Jurakic 2006).

Considered the primary determinants of wear, contact material and use action are targeted in all experimental programs on use-wear. The fact that, in many cases, these investigations have not been carried out systematically and variations exist between experimental programs in the ranges of actions used to work different contact materials, is problematic (e.g. Semenov 1968; Tringham et al. 1974; Keeley 1975, 1980; Anderson 1980; Spear 1980; Lewenstein 1981; Kamminga 1982; Moss 1983a; Vaughan 1985; Akoshima 1987; Levi Sala 1988; van Gijn 1990; Hurcombe 1992; Linder and Folb 1998; Martindale and Jurakic 2006). In reality, comparisons cannot be made between the effects of either contact material or use action on the development of wear because the same actions are not being performed on the same contact materials – comparisons are being made between non-comparable entities. These problems become further compounded by the failure of analysts, noted above, to control for the effects of additional variables recognised to affect the development of wear. Of the 13 variables listed in Table 1 and acknowledged by wear analysts to contribute in some way to the development of wear, none of experimental programs listed controlled more than five of them (see Table 1. exceptions include Anderson 1980; Kamminga 1982; Fullagar and Jones 2004; Martindale and Jurakic 2006). This means that in relation to the experimental programs listed, any comparisons of the development of wear relative to either use action or contact material, also incorporate the unquantified effects of a minimum of between seven and ten additional variables (e.g.}
Tringham et al. 1974; Keeley 1975; Kamminga 1982; Levi Sala 1988; Martindale and Juracik 2006). As a consequence, not one of the experimental programs discussed here is able to provide evidence of a causal relationship between either use action or contact material on the development of wear every result is a combination of effects from a wide range of variables. These problems may be best demonstrated by example.

Kamminga’s (1982) widely referenced (e.g. Fullagar 1986, 1994; Hayden 1990; Shea and Klenck 1993; Odell 1990; Hardy 1999) Over the Edge volume presents an ideal illustration of these problems in view of their far reaching consequences for the subsequent analyses based upon it (e.g. Fullagar 1986; Neumann 1988; Grace 1989-90; Shen 2000; Shea and Klenck 1993; van den Dries and van Gijn 1997; Alvarez et al. 2001; Martindale and Juracik 2006). Kamminga (1982:19) undertook a large experimental program designed to ‘create a corpus of use-wear created under known conditions.’ He argued that the program exercised experimental control over the raw material of the artefact, the actions involved, edge angles utilised and the addition of abrasives. However, the program may, in fact, be characterised by unsystematic experimentation while little or no control was exercised over relevant variables (1982:5). A total of 444 wear experiments on 8 different contact materials in approximately 14 tasks were performed. Of these, approximately 45% involved experiments with wood: 6% chopping, 16% scraping and 9% adzing. A further 23% of experiments involved different actions with kangaroo skin while approximately 10% of experiments involved drilling and sawing bone. As such, the types of motions used and the number of experiments conducted in each action differed with contact material. Importantly, no single action was used on every contact material, therefore making it impossible to make comparisons between wear generated by the same action but on different contact materials. In addition, the testing of some variables more extensively than others inevitably introduced experimental bias, caused by an unfair dominance of some treatments within the experimental program (see Cox and Reid 2000).

Compounding the lack of systematised experimentation is Kamminga’s failure to control important additional variables. While it is not reasonable to expect that analysts will control variables that are currently unknown to impact upon the development of wear, it is reasonable to expect that they will attempt to control known and acknowledged causes of variation. For example, despite noting edge morphology, force during use and contact angle as affecting the nature and type of wear generated through use, Kamminga makes no attempt to control for differences in edge morphology and highlights the difficulties associated with keeping pressure and contact angle constant throughout the working
process. Measurements of degree of use were also varied with each experiment; scraping wood or sawing bone were measured by time, scraping skin and cutting meat were measured according to the amount of material worked, piercing or drilling bone and shells or sawing bone were measured according to the number of holes or the length of the cut produced and so on. No two tools were used in the same action, with the same pressure, contact angle, edge angle or edge morphology or on the same contact material. As such, each of the patterns of wear observed and characterised from this experimental program includes not only the effects of contact material and action but also of varying degrees of pressure, duration of use, contact angle and edge angle. Consequently, not only are the results of the program non-comparable, but they are also unquantifiable. The experimental program precludes the identification of the specific effects of either use action or contact material on the development of wear. Importantly, Kamminga (1982:18) is aware that the ‘experiments were not repeated with all the variables held constant’ and that the results cannot be tested for statistical validity. While Kamminga acknowledges the limitations this places on making statements of causality in use-wear, and of the preliminary nature of his research, these observations have not been noted by the many subsequent analysts who have drawn on his results.

Kamminga’s experimental program, and the flaws inherent in it, exemplifies the current approach to understanding and interpreting use-wear. Despite multiple investigations into the effects of various use actions and contact materials on use-wear, the specific effects of both remain largely unknown. These same problems are recurrent throughout the literature in relation to the additional variables known to contribute to edge wear; raw material type, duration, speed and pressure of use, edge angle and contact angle.

**Raw Material, Edge Angle and Use Variables**

Raw material type and grain size (Vaughan 1985; van Gijn 1990) are widely accepted to affect the development and identification of microwear by impacting on the nature and speed of polish development, with polish thought to appear more quickly on fine grained materials (e.g. Moss 1983a; Vaughan 1981, 1985; Fullagar 1986; van Gijn 1990; Amick and Mauldin 1996; Alvarez et al. 2001). Differences in the fracture properties of various raw materials are also inferred to alter the susceptibility of the edge to use-scarring and the types of scars produced (e.g. Semenov 1968; Keeley 1974a; Tringham et al. 1974; Broadbent and Knutsson 1975; Odell 1977, 1981; Sietzer 1978; Cotterell and Kamminga 1979; Grieser and Sheets 1979; Lawrence 1979; Dumont 1982; Kamminga 1982;
Tomenchuck 1988a). As such, many analysts have kept raw material a constant in experimental studies, with some choosing to master the effects of contact material and action on a single material, before introducing greater variability (e.g. Spear 1980; Lewenstein 1981; Fullagar 1984; Sussmann 1985, 1988; Knutsson 1986, 1988; Aldenderfer 1990; Hurcombe 1992). In these cases, however, the effect of the raw material itself remains unknown, being held as a constant while other variables are tested. A handful of others, have sought to test the specific effects of raw material on the wear patterns developed through tool use, using multiple raw materials in different tasks and on different contact materials, (e.g. Lawrence 1979; Anderson 1980; Kamminga 1982; Aldenderfer 1990; Alvarez et al. 2001; Martindale and Jurakic 2006). In most cases a wide range of activities are performed on multiple contact materials, but are divided between the different raw materials, rather than performing the same activities on each raw material, exemplifying this lack of systematic experimentation (e.g. Anderson 1980; Kamminga 1982; Alvarez 2001). Comparisons between the wear patterns produced in identical use actions and on identical contact materials but with different raw materials cannot, therefore, be made. In addition, with the exception of Lawrence (1979), in none of the experimental programs listed in Table 1 were all other contributing variables held constant. For example, Alvarez et al. (2001) recently conducted a series of experiments investigating the development of wear on stone artefacts involved in the production of rock art engravings. Controlling the experimental raw materials - obsidian and basalt - Alvarez et al. (2001) used 40 different unretouched edges to produce a series of rock art engravings. Experiments were performed in both longitudinal and transverse motions and duration of use was controlled. Intensity and speed of use, pressure, edge shape, edge angle and contact angle, however, remained uncontrolled and unquantified variables with the effects of each incorporated into any observations of difference in the wear patterns that developed on each raw material. Comparisons between experimental programs controlling particular raw materials are equally problematic, as the degree to which each experiment may be regarded as comparable may be questionable. The large degree of variation exhibited between experiments performed within the same program suggesting that even greater variation is likely to exist between artefacts involved in entirely separate programs. The recurrent problems of poor systematisation and inadequate control of variables therefore indicates that, to date, the specific effects of particular raw materials on the development of wear remain unknown and have been confounded by the effects of contributing variables and unable to be compared relative to various functions. Once again, despite calls from a number of analysts to do so (e.g. Hayden and Kamminga 1979; Stafford and Stafford 1979;
The Principles of Wear Analysis

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Millan 1990; van den Dries and van Gijn 1997), any attempts at statistical verification of observed causal relationships are entirely lacking.

Edge angle is the only morphological attribute of the artefact thought to affect both the type and the frequency of wear, particularly in longitudinal motions whereby the size of the angle controls the degree to which the edge can penetrate the worked material (e.g. Tringham et al. 1974; Hayden and Kamminga 1979; Tsirk 1979; Odell 1981; van den Dries and van Gijn 1997). Acute edge angles are argued to penetrate contact materials deeper and more readily than obtuse angles, resulting in a more invasive distribution of polish. Acute edges are also said to be more susceptible to edge fracturing than obtuse edge angles (Tringham et al. 1974; Tsirk 1979; Moss 1983a), with edge damage of any type argued to be rare, regardless of use, if the edge angle is greater than 64 degrees (Keeley 1980).

Differences in scar size, initiation type and termination are also widely argued to be affected by edge angle (e.g. Tringham et al. 1974; Cotterell and Kamminga 1979; Odell 1980; Knutsson 1986; Akoshima 1987; Tomenchuk 1988a; Tomenchuk and Stork 1988; Shea and Klenck 1993). Due to the range of possible variation in edge angle sizes most analysts compare differences between categories of angle sizes (e.g. Semenov 1968; Tringham et al. 1974; Spear 1980; Kamminga 1982; Vaughan 1985; Levi Sala 1988; van Gijn 1990; McDevitt 1994), with most encompassing a 10 degree range. However, the definition and accuracy of the measurement of edge angle represent further complications for investigations into this variable. While, in some programs, edge angle is measured at a point approximately 2-4mm from the edge itself (e.g. Hayden and Kamminga 1979), others measure the angle of the ‘two surfaces that intersect at the working edge,’ (Kamminga 1982:20) otherwise known as the spine plane angle (e.g. Wilmsen 1968; Tringham et al. 1974; Hayden 1979b; Spear 1980). Lack of consistency in the measurement of edge angle occurs not only between experimental programs but within them. Kamminga (1982:20) utilises both these approaches depending upon the shape of the angle being measured and the presence or absence of retouch on the experimental edge. Importantly, measurements of the same edge, using the two different methods, reveal a large difference between the two indicating that differing the process of measurement introduces further variation into edge angle categories. Compounding these problems are issues of accuracy in the measurement techniques themselves, with inter-observer variation in the use of goniometers noted to be high (see Dibble and Bernard 1980). These problems create the potential for edge angle categories to include a larger range of sizes than is defined by each experimental category, meaning that overlaps may exist between groups being compared.
The amount of control able to be exerted over edge angle in experimental processes will necessarily be weakened by the use of categories of 10 degree ranges in angle size, variation in the techniques used to measure angle size and the use of goniometers. Subject to the amount of difference between size categories, the margin of error either side of each range may be sufficient to blur the boundaries between angle categories, dramatically reducing the explanatory power of comparisons between categories of angle size. In addition, the recurrent problems of poorly systematised experimental protocol and failure to control for additional variables in studies investigating edge angle are evident from Table 1 (e.g. Tringham et al. 1974; Keeley 1975, 1980; Spear 1980; Kamminga 1982; Vaughan 1985; Fullagar 1986; Levi Sala 1988; van Gijn 1990). Less than 15% of the programs listed systematically tested the effects of edge angle and, in each of those cases, a number of variables have either failed to be considered or not been controlled. The combined effects of these problems indicate that, as with contact material, use action and raw material, the specific effects of edge angle on the development of use-wear remain unknown.

Duration and speed of use, the pressure applied and contact angle have also been argued to impact greatly upon the wear development, affecting the distinctiveness and intensity of wear development (Hurcombe 1992). Duration of use is considered particularly crucial due to the minimum periods of use required for distinctive characteristics of polish to develop (Dumont 1982; Moss 1983a; Vaughan 1985; Fullagar 1986; Bradley and Clayton 1987; Grace et al. 1988; van Gijn 1990; McDevitt 1994; Korobkov 1999; Skakun 1999). However, increases in the speed or pressure of use are able to shorten these minimum periods, by intensifying use, and producing similar levels of polish development more rapidly (Moss 1983a; Vaughan 1985; Fullagar 1986; van Gijn 1990). Thus, each of these aspects of use can be extremely difficult to interpret individually due to equifinality in wear development, with heavy polish development able to represent both a long period of work or a brief but very intensive one (van Gijn 1990). Due to the likely interrelationship between duration of use, speed and pressure, many analysts prefer to interpret degree of wear rather than duration of use (e.g. Kamminga 1982; van Gijn 1990 as opposed to Vaughan 1985a; Fullagar 1986). The angle at which a tool makes contact with the material is argued to affect the direction of force imposed upon the edge and therefore the orientation of resultant scars (e.g. Speth 1972; Tringham et al. 1974; Tsirk 1974; Cotterell and Kamminga 1979; Lawn and Marshall 1979; Odell 1981; Dumont 1982; Moss 1983a; Fullagar 1986; Akoshima 1987; Tomenchuck 1988a, 1997; Hayden 1990; van Gijn 1990; Shea and Klenck 1993; Alvarez et al. 2001).
Duration of use in experimentation is almost always recorded by analysts and is one of the easiest variables to control, though many analysts have failed to do so (e.g. Tringham et al. 1974; Keeley 1975; Lewnstein 1981; Kamminga 1982; Akoshima 1987; Bradley and Clayton 1987; Levi Sala 1988; McDevitt 1994 for exceptions). By comparison, the human difficulty of maintaining constant pressure, speed and contact angle during use action makes them particularly difficult to control without the use of mechanisation (e.g. Lawrence 1979). While some analysts have attempted to control pressure and contact angle by ensuring that the same person conduct all experiments (e.g. e.g. Kamminga 1982; Moss 1983a; Olausson 1983; Corrucini 1985; Sussman 1985; Hurcombe 1992), others have considered them simply too difficult to control (e.g. Tringham et al. 1974; Fullagar 1986). The combined effects of failure to control contact angle, use duration, pressure and speed has important consequences for the validity of the experimental program conducted. These are illustrated by exploring the experimental protocol utilised in the seminal and widely referenced work by Tringham et al. (1974) (e.g. Patterson 1981; Fullagar 1984, 1986; Siegel 1984; Bienenfeld 1985; Bettison 1985; Corrucini 1985; Akoshima 1987; Richter 1996; Madsen 1997; Shen 2000; Stemp and Stemp 2001). In this study, each artefact was used for 1000 strokes and examined and photographed at several intervals throughout. In most cases, a unidirectional movement counted as one ‘stroke.’ In the case of ‘sawing’ however, each bi-directional movement back and forth counted as one ‘stroke’ (Tringham et al. 1974:184).

As such, edges used in sawing actions were exposed to twice the amount of contact with the material than those involved in scraping actions, making it impossible to compare the development of wear from each on equal terms. Importantly, failure to establish a consistent stroke length for all experiments will have introduced greater variation in the amount of time each artefact was in contact with the worked material, with some stroke lengths likely to be much longer than others, with any differences doubled when involved in sawing activities. Further, by involving several analysts in conducting experiments, differences in the pressure and speed of use, as well as stroke length, and contact angle between experiments were also inevitable. As such, each of the experiments conducted by Tringham et al. (1974) are subject to a wide range of uncontrolled variability; use action, contact material, contact angle, edge angle, contact angle, pressure, speed of use and duration of use (see also Anderson 1980; Fullagar 1986 for identical experimental protocol). The previously identified inability to identify causal relationships between wear and any one of these variables, or to draw comparisons between them, is symptomatic of these problems in experimentation.
These investigations into the experimental processes upon which current principles of wear analyses are based reveal several fundamental and far reaching flaws in experimental protocol. The generation of a series of unsubstantiated claims relating use-wear to artefact function has been one consequence of the failure by analysts to systematically test relevant variables, control the effects of additional variables known to affect wear and to verify their results through repetitive testing. The inclusion of substantial variation within multiple relevant variables in each experimental program precludes the identification of specific causes of wear. A second consequence is that, contrary to the widespread claims of the characterisation of wear (e.g. Odell 1975; Hayden 1979c, 1990; Keeley 1980; Odell and Odell-Vereecken 1980; Sussman 1985, 1988; Aldenderfer 1990; Borras 1990; Shultz 1992; McDevitt 1994; Grimaldi and Lemorini 1995; Korobkova 1999; van den Dries and van Gijn 1997; Donahue and Burrini 2000; Alvarez et al. 2001), the specific effects of these variables are largely unknown, confounded by the effects of unidentified and uncontrolled variables.

It seems possible, in light of these problems, that recorded discrepancies between the appearances of various polishers, scar frequencies and scar features are the product of building comparisons between non-comparable experiments. However, a second possibility is that additional sources of variation are occurring from variables that hitherto have failed to be investigated. That is, if causes of overlap or difference cannot be identified from amongst known variables, it seems possible that they are the product of variables that have not yet been identified and that are worthy of investigation. These are discussed below.

UNIDENTIFIED VARIABLES

While a great many experimental programs have been carried out investigating wear development, none have explicitly tested for sources of wear patterning that are not directly related to use. As discussed above, edge angle has been widely attributed to impact on the frequency, size and type of scars generated. Yet wear analysts have entirely neglected experimention with any other point of morphological difference between functional edges. Causal observations/comments by analysts divide edge morphology into three components: plan, profile and section. Plan and profile refer to the shape of the edge when viewed from above and from the side respectively (see Figure 1), and are described as either convex, concave, straight or a combination of these shapes. Edge section relates to the shape of the two surfaces which meet at the working edge when viewed in section. An
edge may represent any of nine combinations of straight, concave and convex shaped dorsal and ventral aspects. The idea that edge morphology contributes to wear patterning is supported by three lines of evidence: 1) core and blank reduction theory, 2) fracture mechanics and 3) observations made by wear analysts themselves. Each of these lines of evidence is discussed below, revealing that failure to explore morphological variance as a source of wear patterning is likely to have been a costly oversight by wear analysts with important consequences for the field.

Figure 1. Differences in edge shape relative to plan and profile. The area between A and B marks the edge shape referred to in each case.

Research into the effect of core morphology on the manufacture and reduction of flake blanks indicate, on a macroscopic level, the processes likely to occur to edges on a microscopic level through use (Cotterell and Kamminga 1987). Designed to explore how core 'morphology may influence the conservation and transport of lithic materials' (Pelcin 1997:749), these studies represent some of the most highly controlled experiments investigating the relationship between core and flake morphology, with important implications for the development of wear (e.g. Speth 1981; Dibble and Pelcin 1995; Pelcin 1997; MacGregor 2007). Differences in flake size, including length, width, thickness, shape and bulb of percussion have been found to be the product of difference in core morphology (Pelcin 1997). In addition, the overall sizes of the artefact and the edge angle
used have an important effect on the size and shape of scars produced (Speth 1981; Dibble and Pelcin 1995). These discoveries indicate that edge morphology is likely to have a significant effect on the size and type of scars produced through wear, given that 'a major and undeniable factor influencing flake morphology is the morphology of the flaking surface' (Dibble and Pelcin 1995:436). A further observation made in studies of blank morphology has been that the velocity and mass of the indentor used are negligible in their effects on flake morphology (Dibble and Pelcin 1995:436), with core morphology and platform angle shown to be greater determinants of flake morphology. During use, the removal of flakes from the functional edge occurs as a result of the contact material acting as the indentor. If differences between the velocity and mass of the indentor can be shown to have a negligible effect on the type of scars produced in core reduction, it may be that contact material is likewise only minimally responsible for the patterns of scarring produced during use. Instead, morphology and other use related variables may represent the greater contributors to scar patterning. The fracture mechanics literature is similarly supportive of morphology as a primary determinant of wear by directing applied force.

Concepts of fracture mechanics are often used by analysts to support the validity of edge-scarring in the interpretation of wear (e.g. Tringham et al. 1974; Kamminga 1979; Tommenchuck 1979, 1988a, b, 1997; Tsirk 1974, 1979; Odell 1981; Shea and Klenck 1993). The effects of degree and direction of force, indentor hardness (but see above), edge angle and raw material are each discussed in the use-wear literature and argued to be supported by fracture mechanics, with studies by Kamminga (1979) and Cotterell and Kamminga (1987) particularly widely cited (see also Speth 1972; Tsirk 1974; Lawn and Marshall 1979).

However, what is overlooked is that in use processes, edge shape as well as contact material and use action, will invariably affect both the amount and direction of applied force. For example, differences in edge plan such as concave, convex or straight, necessarily distribute force differently across the working edge. If we assume the same force is applied to each edge, convex edges invariably focus that full force onto a single contact point (see Figure 2). This same force is divided between two contact points on either side of the concavity when using a concave edge and is distributed evenly across the entire length of a straight edge plan. Invariably, despite the application of the same force, different amounts of pressure will be acting upon the edge according to its shape and the area of the edge over which that force must be divided. Given that greater force is expected to produce a greater number of scars (e.g. Tringham 1971; Tringham et al. 1974; Keeley 1975; Tsirk 1979; Odell 1980, 1981; Odell and Odell-Vereecken 1981; Spear 1980; Bienenfield 1985; Tommenchuck 1988a,b, 1997; van Gijn 1990; Shea 1992; Becker and
Wendorf 1993; McDevitt 1994; van den Dries and van Gijn 1997) it may be that edges that are convex in either plan or profile scar more frequently than either concave or straight edges. In addition, the focus of force on an isolated point on convex edges may result in a more localised, rapid and intensive polish development than would be produced under identical circumstances with an edge that is straight in plan or profile. The current dependence of wear analyses on both the nature and number of scars produced during use and the location and distribution of wear, means that variables such as plan shape and longitudinal profile are likely to have an important effect on the appearance and interpretation of wear that heretofore has been unaccounted for.

Figure 2. Points of contact for concave, convex and straight edges respectively. Whether in plan or profile, force will be divided between only two contact points on concave edges, one on convex edges and the entire length of straight edges, during use. Where force is constant, the pressure resultant on each of these edges will differ considerably with contact area.

Observations made by wear analysts themselves, but which have been largely ignored for experimental purposes (e.g. Odell 1975, 1981; Hayden 1977; White et al. 1977; Cotterell and Kamminga 1979; Patterson 1981; Moss 1983a,b, 1997; Knutsson et al. 1988; Levi Sala 1988; Grace 1990; Shea 1992; Shea and Klenck 1993; Grace 1996; Hogberg 2000; Grimaldi and Lemorini 1995; Lemorini et al. 2006), represents the third line of evidence suggesting edge morphology may affect the development of use-wear. A number of analysts have noted strong correlations between particular edge morphologies and the functions ascribed to them in archaeological assemblages (e.g. Cantwell 1979; Moss 1983a; Knutsson et al. 1988; Fullagar and Jones 2004; Grimaldi and Lemorini 1995; Lemorini et al. 2006). The susceptibility of different edge shapes in plan to scarring mentioned above has also been noted by wear analysts in a performance context, with straight edges found to be less susceptible to edge damage than are concave or convex shaped edges (e.g. Tringham et al. 1974; Tsirk 1979; Moss 1983a, 1997; van Gijn 1990). Van Gijn (1990) also identified a strong relationship between the shape of an edge in section and inferred motion. Edges that were straight along both aspects of the working edge were more often used in longitudinal activities while those with combinations of concave or convex shaped aspects
tended to be used for more generalised scraping activities. Yet quantification of these effects remains unknown, with analysts failing to investigate edge morphology as an additional experimental variable. In combination, the evidence provided by blank and core reduction theory, fracture mechanics, and direct observation, provide strong support for the suggestion that edge morphology plays an important role in the development and location of wear on used artefacts. Failure to account for the effects of morphological variables in the construction of principles of wear analyses may be further compounding the recurrent problems with experimental protocol identified earlier in this chapter. Various aspects of edge morphology may represent additional causes of variation to the development of edge wear which experimental protocol has failed to control or quantify; adding to the already large numbers of similarly uncontrolled/unquantified variables contributing to wear patterns previously attributed to use action or contact material alone.

CONCLUSION

This chapter has identified multiple problems with current approaches to the identification of artefact function through wear analyses. It has been suggested that the widespread faith currently placed on the principles of use-wear analysis may be misguided in view of the unquantified, unsystematic and uncontrolled experimental data upon which they are based. At present, analysts are not only unable to demonstrate that real differences exist between polishes generated by different materials but also whether it is, in fact, the contact material worked and not one of any number of other variables that is responsible for differences in the appearance of polish or scar types. In addition, it cannot be confirmed that all possible relevant variables affecting wear development have been identified and explored, with failure to investigate edge morphology likely to be an important oversight. These problems have important consequences for the accurate identification of artefact functions through wear as, well as the validity of interpretations of archaeological sites based upon them. The construction of site interpretations based on wear analyses are the topic of the following chapter.

The failure of earlier generations of analysts to evaluate the principles upon which their research is based has meant that subsequent generations of analysts have repeated earlier mistakes, with experimental programs subject to identical flaws in protocol, rather than improving the reliability of the method. Of greater concern is the fact that current principles have become so tacitly accepted that some analysts no longer feel the need to conduct their own experiments, simply referencing the untested results of others (e.g.
Siegel 1984; Knutsson et al. 1988; Shultz 1992; Madsen 1997). These problems reveal a need for highly controlled and systematic experimentation in order to generate accurate and comparative data. The adoption of appropriate experimental protocol, reinvestigation of acknowledged variables in accordance with improved protocol and continued exploration of potential sources of variation in wear must therefore be considered imperative if analysts are to ensure that the technique is robust and that its contributions to archaeological interpretation are valid.
CHAPTER 3

USE-WEAR IN ARCHAEOLOGICAL INTERPRETATION

INTRODUCTION

The previous chapter identified a range of problems inherent in current approaches to the identification and interpretation of wear on the used portions of stone artefacts; problems that indicate a need for further and more controlled experimentation. This chapter explores the use of functional ascriptions of artefacts from wear in the construction of interpretations of archaeological sites. Wear analysts use individual artefact functions to interpret specific activities carried out at sites, identifying changes in site activities, both spatially and chronologically, through comparisons of the functional composition of different sites, based on the relative frequencies of specific functional markers. This chapter reviews current approaches to the interpretation of individual artefact and site functions and the principles underlying them, identifying a number of fundamental misconceptions and inadequacies in these approaches and outlining important areas for research.

FRAMEWORKS FOR INTERPRETING ARTEFACT FUNCTION

Typological Systems

Typological frameworks and the relative merits and problems associated with them have been extensively discussed and debated in the archaeological literature (e.g. Dunnell 1971, 1986; Hill and Evans 1972; Jelinek 1976; Gallus 1977; Thomas 1981; Cowgill 1982; Read 1982, 1984; Spaulding 1982; Voorups 1982; Whallon 1982; Dibble 1985, 1995; Beck and Jones 1989; Adams and Adams 1991; Read and Russell 1996; Cross 1999; Hiscock 1981, 1998, 2001; Bisson 2000; Shott 2003). Concerns include the arbitrary and unquantified nature of type divisions (e.g. Hill and Evans 1972; Dickson 1976; Jelinek 1976; Cowgill 1982; Villa 1983; Dunnell 1986; Beck and Jones 1989; Barton and Neeley 1995; Bisson 2000), with explanations for the basis of differentiation between forms distinctly lacking. For example, the Bordesian typology divides types either on the basis of outline shape (i.e. burins, notches or denticulates), presumed function (i.e. scrapers, knives), resemblance to natural objects (i.e. leaf shaped points, slugs) or production technology (e.g. Levallois...
flakes) (Bisson 2000). Further, types are defined by as few as one attribute or as many as five, based on the presence or absence of retouch, the type of retouch, surface affected and number and location of retouched edges and edge-angle (Bordes 1969; Bisson 2000; Debénath and Dibble 1994). Similar problems have been identified in McCarthy et al.’s (1946, McCarthy 1976) Australian typology (e.g. Hiscock 1981, 1983, 1998, 2004, in press; Collins 2001; Clarkson 2002a) again with some types differentiated on the basis of presumed function (e.g. saws, drills, knives and scrapers), morphological symmetry (e.g. juan knife vs leilira blade), location of retouch (e.g. knives and chisels) type of retouch (e.g. unifacial vs bifacial points) and presumed value of the items (e.g. ‘normal flakes and blades’ are differentiated from specialized types within the classification of ‘clouera’ and ‘tulas’).

Similarly inconsistent divisions are noted within American classifications with some divisions made on the basis of plan shape, others beveling, the presence or absence of teeth or the rationalization by ethnographic observation (Dunnell 1986). Ritchie’s (1961) ‘Projectile Point Typology’ typifies this approach with divisions made first on the basis of function (i.e. dart points vs spear points vs hand held thrusting weapons), followed by variation in form relating to size, proportions and retouch characteristics and finally on the basis of cultural, spatial or temporal considerations (Ritchie 1961:7). Further criticisms relate to the focus on describing the central tendency of a type and have been argued to highlight differences between types while largely concealing that which exists within them (e.g. Mason 1967; Mellars 1970; Bamforth 1991a; Shott 1994; Barton and Neeley 1995; Dunnell 1996a; Bisson 2000; Clarkson 2002; Hiscock in press). The utility of ‘types’ as a unit of measurement has also been questioned with some arguing that artefact function relates to the features of the specific edge rather than to the overall morphology of the artifact, suggesting that it is edge and not artifact morphology that should differentiate artefacts (e.g. White 1967; White and Thomas 1972; Knudsen 1973, 1978, 1979; Dumont 1987; Knutsson et al. 1988; Shea 1988; Shen 2000). A further criticism is that the role of different raw materials (e.g. Tringham 1971), reduction processes (e.g. Frison 1968; Jelinek 1976; Dibble 1995), blank morphologies (e.g. Bamforth 1986, 1991a) and environmental constraints (e.g. Binford 1972) as defining variables affecting implement morphology cannot be accommodated by some typological classifications (e.g. Flenniken and Raymond 1986; Flenniken and Wilke 1989; Barton and Neeley 1995; Cross 1999). These criticisms have lead to the suggestion that important relationships between ‘morphology, raw material, function and tool life-history’ are masked by typologically imposed ‘uncontrolled mixture of attributes’ (Bisson 2000:2). The large body of literature discussing the relative merits and disadvantages of typological classifications means that it is not necessary to
discuss these ideas any further in this thesis. However, the focus of this thesis upon the investigation and interpretation of stone artefact functions and the heavy dependence of current approaches upon typological concepts necessitates some discussion of the effect of typological concepts as they relate specifically to the generation of functional interpretations of stone artefacts.

Use-wear analyses are heavily guided by, and proceed within, traditional typological frameworks. These frameworks were established within culture-historical frameworks as means of relating stone artefacts to one another, both spatially and temporally, by grouping artefacts according to similarity or difference in morphology (Bisson 2000; Hiscock and Attenbrow 2005); essentially enabling the identification of cultural and temporal markers (Ritchie 1961; Bordes 1969; Hill and Evans 1972; Thomas 1981; Brown 1982; Spaulding 1982; Vierra 1982; Flenniken and Wilke 1989; Barton and Neeley 1995; Cross 1999; Schmitt 1999). Central to typological thinking is the assumption that artefact morphologies are the end product of an intentional design manufactured by the knapper to fulfill specific needs (Short 1989; Dibble 1995; Bisson 2000; Hiscock in press). This idea is exemplified by statements of intent such as ‘the production of the semi-discoid or tongue-shaped tula is the principal aim of the knappers’ (McCarthy 1976:27), ‘the end product of the analysis approximates in important formal respects the ideal or norm of the maker’ (Ritchie 1961:8) and ‘morphological typology then, allows one to evaluate, at one and the same time, the implement needs of man, such as he conceived them’ (Bordes 1969:2). Artefact morphologies are therefore considered to represent a set of desired characteristics that reflect the original goals of the knapper, more specifically, his ‘mental template’ (e.g. Ritchie 1961; Cowgill 1967; Chang 1967; Gallus 1968, 1977; Thomas 1981; Mellars 1989; Hester 1993). As such, typological divisions are believed to be natural, real and inherent in the material, possessing significance within themselves (e.g. Kreiger 1944; McCarthy et al. 1946; Spaulding 1953, 1982; Ford 1954a, b; Ritchie 1961; Hole and Heizer 1964; Deetz 1967; Bordes 1969; McCarthy 1976; Cowgill 1982; Read 1982; Whallon 1982; Mellars 1989; Hester 1993 see also comments by Hoffman 1985; Dunnell 1986; Bisson 2000). Morphological differences between types are therefore seen to reflect stylistic (e.g. Bordes 1969; Tringham 1971; Jelinek 1976; Sackett 1977; Brown 1982; Read 1982; Mellars 1989), cultural (e.g. Leakey 1951 in Oakley 1956; Bordes 1961; Ford 1962; Hole and Heizer 1965; Mellars 1970, 1989; Binford 1972; Spaulding 1977, 1982; Thomas 1979; Brown 1982; Read 1982), temporal (e.g. Clewlow 1967; Bettinger and Taylor 1974; Bettinger 1975, 1977; O’Connell 1975; Thomas et al. 1976; Heizer and Hester 1978; Thomas 1981; Mellars 1989; Hester 1993 see also Cross 1999) and/or functional difference (e.g. McCarthy et al. 1946;
Mitchell 1949; Clark 1959, 1967; Posnansky 1959; Kleindienst 1961; Mason 1967; Bordes 1969; Binford 1972; Isaac 1972; Dickson 1976; McCarthy 1976; Gallus 1971, 1977; Sackett 1977; Whallon 1982; Davis and Keyser 1999 see also comments by Shott 1989; Bisson 2000; Dibble 1995). This emphasis on intention and design implies that every stage in the production of the artefact is preconceived, each representing a step closer to the final desired end product. Artefact types are therefore argued to be discrete and static in that all members of the same type fulfill the same role. If morphological difference is attributable to functional difference, then similar morphologies equate to similar functions (but see Read 1982). Within any class, certain forms are believed to approximate 'ideal' examples of the knapper's mental template, with variations from these ideals regarded as 'aberrant objects resulting from accidents of the chipping process, perhaps from technical difficulties with the material' (Ritchie 1961:9) or 'noise' (e.g. Read 1982; Spaulding 1982; Mellars 1989; see also comments by Mulvaney 1977; Dunnell 1986; Bamforth 1991a; Barton and Neeley 1995). The most commonly used principle is the idea that the more heavily an artefact is retouched the more closely the artefact is believed to approximate the knapper's design (e.g. McCarthy et al. 1946; Ritchie 1961; Bordes 1969; McCarthy 1976 see also Flenniken and Wilke 1989; Cross 1999; Clarkson 2002; Hiscock in press). Retouch and design have tended to be considered synonymous with use and are argued to be indicative of 'tools', with unretouched flakes regarded as 'taxonomically irrelevant,' (Isaac 1968:768), lacking signs of design or intent. Retouch is suggested to fulfill a number of roles on stone tools. In some cases, retouch will indicate the functional edge or 'active part' of the tool (Bordes 1969:3) while, in other cases, it is thought to represent the 'part ofprehension' in which an edge is shaped by retouch to facilitate prehension (Bordes 1969; Tringham 1971). The determination of retouch as either 'active' or for the purposes of prehension was therefore commonly decided by the nature of the retouch and ideas about how the tool should be and was intended to be used (Bordes 1969; see also Bisson 2000). In many cases, ethnographic analogies were used to identify artefact functions or illustrate actions and became incorporated into typological classifications (e.g. McCarthy et al. 1946; Bordes 1967 see also comments by Hill and Evans 1972; Mulvaney 1977; Bisson 2000; Collins 2001; Hiscock in press). For example, "a backed blade (or a blade with a blunted edge) resembles a penknife blade that one can deduce the function 'knife' likening the unretouched edge to a cutting edge and the edge blunted by steep retouch to the back." (Bordes 1969:3). Specific forms were therefore believed to be manufactured to fulfill a specific function, with all members of the same class fulfilling the same function. The
adoption of/belief in the validity of these typological assumptions has had important consequences for wear-analyses.

For many wear analysts, the purpose of interpreting use-wear is ‘to see if artefacts which have the same shape are all used for the same task and to discover what that task was’ (Hurcombe 1992:79). However, the time-consuming nature of wear-analyses means that analysts are necessarily restricted in the number of artefacts that they are capable of analysing from any one assemblage (Keeley 1975; Anderson-Gerfaud 1981; Moss 1983a; Fullagar 1986; Levi Sala 1986, 1988; Aldenderfer 1990; van Gijn 1990; Hurcombe 1992). Time must be concentrated where the results will be most profitable and, as such, analysts must identify which artefacts will give the greatest return for that investment of time. As such, many analysts draw on typological concepts to provide guidance and to target, more specifically, the search for wear. Examples of wear-studies investigating the functions of specific implement types include burins (e.g. Kamminga 1982; Kay and Solecki 2000), borers (e.g. Dumont 1987), drills (e.g. Yerkes 1983; 1993; Grace 1989-90; Aldenderfer 1990; Linder and Folb 1998), points (Shea 1993; Neumann 1988; Nuzhnyi 1990; Crombe et al. 2001), sickles (e.g. van Gijn 1987, 1999; Korobkova 1999; Skakun 1999), microdenticulates (Juel Jensen 1988a), adzes (e.g. Spenneman 1986) and scrapers (e.g. Broadbent and Knutsson 1975; Brink 1978; Cantwell 1979; Salls 1985; Siegel 1984; Kazarjan 1990). This approach invariably has several implications for wear-analyses, the most important being that, in many cases, the approach can no longer be regarded as an independent and unbiased test of typological classification. For example, many analysts focus the search for wear on known types or heavily retouched forms with minimal, if any, attention given to unretouched flakes. This means that a large and important (Shott 1994) proportion of most assemblages remain entirely unanalysed. In addition to identifying specimens for wear, assertions of which was the functional edge for each artefact type meant analysts could further restrict the search for wear to these functional edges (e.g. Kazarjan 1990; Lindner and Folb 1998; Korobkova 1999; Skakun 1999). The suggestion that all members of the same class performed in the same way justified only a handful of specimens of each type being analysed to identify functions for the class as a whole (e.g. Dumont 1987; Aldenderfer 1990; Kazarjan 1990; Lindner and Folb 1998; Korobkova 1999; Skakun 1999).

Whilst time-effective for analyses, an essential problem with using typological ideas as a basis for analysis, is that the central assumptions upon which typological classifications are based have not been adequately tested (Dibble 1995; Bisson 2000; Collins 2001; Clarkson
2002; Hiscock in press). Though uniquely positioned to provide an independent means of testing typological assumptions, the current approach of allowing typological assumptions to guide and, in the case of identifying the functional edge, limit the search for wear, has prohibited wear-analyses from independently testing typological theory. For example, the restriction of the search for wear to specific implement types, governed by the assumptions that unretouched flakes fulfilled no function, tends to limit the discovery of contradictory evidence of use on the edges of unretouched flakes by dramatically reducing the number of investigations into this class of artefact. The restriction of analysis to a single assumed functional edge similarly prohibits the discovery of multiple used edges on artefacts. Likewise, the decision to analyse only a handful of members of the same class, predicated on the assumption that all members of the same perform the same function, dramatically reduces the chances of identifying a range of different functions from members of the same class by reducing the number of members of that class subjected to analysis. It must therefore be recognised that, instead of independently testing the validity of typological assumptions, wear-analyses are in fact reinforcing them by allowing these ideas to restrict their own interpretive framework.

A final typological assumption with important implications for wear-analyses relates to artefact performance; that is, the implicit belief that because artefacts were manufactured to a specific form and to fulfill a specific function, they are invariably capable of performing these tasks to a high level. Assumptions of artefact efficiency are predicated on the assumption that 'change is directly connected with function and performance. It is dissatisfaction with performance (i.e. with the current level of efficiency) which prompts an artisan to change his tool... The old form is still (until the particular moment of creation of the new) the then known best, most efficient, practical solution which is attainable... It is still the perfect model extant, relative to the position in time and space of the maker' (Gallus 1977:140-141 see also Tringham 1971; Sackett 1977; Read 1982). The belief that types reflect task specific designs, accompanied by general suggestions of which morphologies are best suited to particular tasks (e.g. McCarthy et al. 1946; Bordes 1969; Mellars 1970; McCarthy 1976; Gallus 1977; Read 1982; Hayden 1990:92; Kazarjan 1990; Grimaldi and Lemorini 1995) has meant analysts have rarely felt the need to identify what, specifically, makes a particular morphology suitable for its chosen task. As a consequence, differences in morphological characteristics, as they relate uniquely to a particular artefact function, are unknown. Investigations into whether or not an artefact is capable of performing the task ascribed to it or whether alternative forms might be more productive are also absent from the literature. As such, analysts attempt to identify what an artefact
was used for, without knowing why it was used in a particular way or what specific combination of morphological features lends itself to a particular task. Artefact performance represents a crucial component of artefact function that has been entirely missed from the wear literature; that is the ability of artefacts to perform the tasks interpreted of them or to characterise the relationship between morphology and function.

A handful of analysts have appeared to ignore the emphasis on retouched artefacts advocated by typology, including unretouched flakes amongst the artefacts for analysis (e.g. Vaughan 1985; Fullagar 1986; Juell Jensen 1986; Dumont 1987; Bienenfield 1988; Knutsson et al. 1988; Aldenderfer 1990; Moss 1997; Shen 2000; Lemorini et al. 2006). In a few cases, the decision to analyse both retouched and unretouched artefacts represented a response to the increasing number of observations of unretouched flakes being used in a wide range of functions in ethnographic contexts (e.g. Gould, Koster and Sontz 1971; White and Thomas 1972; Hayden 1977; White et al. 1977), such as Knutsson et al (1988), Moss (1997) and Lemorini et al (2006). However, despite the appearance of independence from typological constructs, the decision to include unretouched flakes in wear-analyses has tended to be either a forced product of assemblage composition, a compromise within the typological approach or necessitated by the research questions being asked. For example, the decision to include unretouched flakes was made easy for some by the dearth of retouched forms present in the assemblage under analysis (e.g. Fullagar 1986), while for others, the purpose of investigating unretouched flakes allowed analysts to investigate both ‘waste and final products’ (Dumont 1987) within a traditional typological framework (e.g. Dumont 1987; Bienenfield 1988). Aldenderfer (1990), however, considered unretouched and retouched flakes to represent two different categories of tools. For unretouched flakes, only the edge was considered important, whilst for retouched types the entire morphology of the artefact had significance. Drawing on Bleeds’ (1986) theory of ‘maintainable versus reliable’ design systems (maintainable and reliable design systems are discussed in detail in the following chapter), Aldenderfer explored the extent to which unretouched flakes represented maintainable systems and retouched types indicated reliable design systems. Aldenderfer’s model, therefore, represents a confluence of ideas in which an attempt is made to embrace new concepts without negating or abandoning traditional typological concepts.

A second area of deviation from typological norms has been the occasional rejection of the ‘type’ as the fundamental unit of analysis. Instead of restricting the search for wear to assumed functional edges, the entire periphery of the artefact edge is scanned to identify use zones and analyse them independently of the entire artefact, allowing one implement to
have been used in a number of functions (e.g. Knudson 1973, 1978, 1979; Vaughan 1985; Knutsson et al. 1988; Shea 1988; van Gijn 1990; Shen 2000; Lemonnier et al. 2006). For each identified use zone, determinations of contact material and use are made separately before an interpretation is made of the tool as a whole. The approach views implements and assemblages in terms of their basic functional components, as well as a technological entity (Odell 1981a). These studies have been designed to accommodate the observations that, in recent tool using groups, 'edge characteristics have proved to be the main criterion for the selection of functional flakes' (Knutsson et al. 1988:278). As such, investigations of separate use-zones specifically investigate the relationship between individual use-edges and function. However, despite allowing for the possibility of multiple functional edges or multifunctionality of tools, tool form is still often believed to be intentional and reflective of a knapper's design; it is simply the case that knappers designed multifunctional tools (e.g. Odell 1981a). This reluctance to separate the functional ascription of artefacts from typological ideals is recurrent in wear-analyses.

Interpretations of site function and inter-site/inter-regional comparisons are similarly restricted by adherence to typological assumptions. Having identified individual artefact functions in accordance with the system outlined above, and based usually on a small sample of retouched artefacts from the assemblage recovered, analysts construct interpretations of the functions carried out at the site. The recognition of different types, with ascribed functions, become markers with spatial or temporal changes in the relative frequencies of these markers used to indicate changes in site usage over time or by comparison with other sites in the area (e.g. Binford and Binford 1966; Lewenstein 1981; Caneva et al. 1996; Kealhofer et al. 1999). Collections of artefacts found in association with one another, performing similar or related tasks, are interpreted as activity areas within sites (e.g. Lewenstein 1981; Moss 1983a; Aldenderfer 1990; Knutsson et al. 1990; Caneva et al. 1996; Shott 1989; Shen 2000; Fullagar and Jones 2004). Assemblages that exhibit a narrow range of functional variation, as evidenced by type frequencies, are interpreted as activity-specific or specialised sites while greater variability in forms and associated functions are argued to reflect the performance of generalised activities such as those carried out at a base camp (e.g. Binford and Binford 1969; Conkey 1980; Binford 1983; Bienenfield 1985; Aldenderfer 1990; Kazarjan 1990; Hogberg 2000; Shen 2000). The presence of a greater number of hide-working implements relative to wood-working has also lead to simple statements regarding the quantities of material processed on site and so on (e.g. Keeley 1980). Under uncontrolled experimental circumstances, analysts have derived qualitative statements regarding the amount of use an edge is able to withstand in a
given function before being regarded as dull, and extrapolated from this to determine the amount of that same material likely to have been processed by the artefacts representing function at the site (e.g. Korobkova 1981, 1999; Richter 1996). In essence, the form is argued to represent the function, while the relative frequencies of the form and associated function are thought to indicate the intensity of that function at the site. In almost all cases, interpretations of site function have comprised simple and direct counts of the number of functions thought to have been performed at a site over time, as reflected by variation in artefact morphology.

Crombe et al.'s (2001) recent article on the function of microliths at the Verrebroek site, Belgium, exemplifies current approaches to site interpretation from wear. Six different microlith types, divided on the basis of location of retouch, were included in the study, with morphological variation stated to be the product of functional, social or chronological variation (Crombe et al. 2001:256). Microscopic analysis of wear revealed that, despite greater morphological variation, only two functional groups were represented by the microliths: barbs and tips. Yet, regardless of the identification of functional overlaps between different types, the analysed microliths are recombined with the assemblages from their relevant loci. Crombe et al. identify three broad assemblage types on the basis of the dominant microlith morphological types present in each. Regardless of the additional types or unretouched flakes contributing to the composition of these assemblages, they are defined by domination of triangle, crescent or point shaped microliths. Each of these assemblages included several of the six microlith types analysed for wear, indicating that, in many cases, different morphological types were simultaneously used to fulfill the same function. Having eliminated function and chronology as determinants of morphological difference, Crombe et al. conclude that ‘A possible explanation is that during the Preboreal, barb typology and exotic materials were markers of group affiliation within the settlement’ (2001:263). This conclusion typifies the narrow interpretive capabilities of approaches dependent upon typological frameworks. The focus upon specific morphological types means that the majority of artefacts within these assemblages are unconsidered, with interpretations being constructed on unrepresentative data. While there is no way of knowing the range of functions represented by these unconsidered members of the assemblages, the existence of observed overlaps in functions between types (e.g. Cantwell 1979; Tomenchuck 1988b; Aldenderfer 1990; Hayden 1990; Becker and Wendorf 1993; Grimaldi and Lemorini 1995; Caneva et al. 1996; Skakun 1999; Shen 2000) suggests it is possible that differences in assemblage composition do not represent functional difference but simply differences in reduction strategies or technological systems.
However, typological frameworks are not built to allow explanations of variation of this sort. The idea of ‘types’ as static, unchanging and the product of social, chronological or functional difference only, precludes the possibility that technology represents a dynamic and interactive contributor to hunter-gatherer subsistence. The idea that technology may change in response to a range of factors impacting upon behavioural and subsistence systems, simply cannot be accommodated by typological frameworks. As a consequence, in the absence of chronological or functional explanations for difference, Crombe et al. (2001) are forced to explain difference by the only remaining source typology allows for: cultural markers. This static concept of artefact manufacture and use inevitably results in static interpretations of the behaviour that generated and used them. While these types of interpretations contribute, at some level, to our understanding of prehistoric activities and are not necessarily a problem, they are narrow in focus, and add little to broader based behavioural theories of hunter-gatherer subsistence. They are, however, inevitable in the absence of information regarding the interaction between artefact form and function. Without an understanding of the way performance and function changes with shifts in morphology it is impossible to relate artefact function and its physical manifestations to subsistence behaviour, or to identify them in the archaeological record.

Within a typological framework, the approaches to wear-analysis outlined above are acceptable and accord with the general goals established for the field. The self-reinforcing nature of the wear-analyses becomes immaterial if typology may be shown to accurately account for artefact morphology. If typological systems are reliable indicators of the relationship between form and function then any associated limitations are irrelevant. However, in order to know this, truly independent tests of typology are required.

TESTING TYPOLOGY

The explicit nature of the assumptions on which typology is based means that hypotheses can be readily established and tested. At a basic level, typological assertions predict that:

1. Artefacts with similar morphologies (classified as the same type) perform the same function. That is, all members of the same type will be found to perform the same function irrespective of spatial or temporal difference according to the knappers design.
2. Retouched flakes will be found to perform different functions from those performed by unretouched flakes, reflecting the differences between the specialized and unspecialized tool forms and their functions.

Forty years ago, Semenov (1964:89) noted that ‘tools can be very different in shape and yet have exactly the same function.’ However with increasing credence given to typological frameworks for thinking about artefact form, wear analysts in general have failed to explore or build upon, Semeov’s original results. Throughout the wear literature analysts note a lack of consistency in the relationship between specific implement types and their functions (e.g. Dunn 1984; Siegel 1984; Dumont 1987; Neumann 1988; Anderson-Gerfaud 1990; Moss 1983a). In general, these represent casual and unexpected observations in which analysts are surprised to find that artefacts with the same form do not always perform the same function (e.g. Lewenstein 1981; Siegel 1984; Dumont 1987; Shea 1988, 1992; Grimaldi and Lemorini 1995; Caneva et al. 1996; Martindale and Jurakic 2006). While key figures have accepted, theoretically, that there may not be a connection between form and function (e.g. Semenov 1964; Frison 1979; Hayden 1979b; Hayden and Kamminga 1979; Schiffer 1979; Knutsson et al 1988; Shea 1988, 1992; Aldenderfer 1990; Knutsson 1990; Shen 2000), it has not been followed up by subsequent analyses. The inherent belief in the validity of typological classifications has become so pervasive that, even when contradictory evidence is noted, analysts appear to be unsure how to deal with it, such that wear-analysis as a field has failed to take these observations into consideration in the analysis of subsequent assemblages.

Investigations into the functions of individual types have resulted in the identification of a range of actions and contact materials on different members of the same implement type. ‘Blades’ and ‘truncated blades,’ are noted to have been used on antler (Cahen et al. 1980), hide, wood and bone (Vaughan 1981; Juel Jensen 1982) and are recorded to have performed a range of actions including boring, cutting and scraping. Burins and endscrapers are similarly identified as showing wide functional diversity (Keeley 1980; Vaughan 1981; Juel Jensen 1982; Gendel 1982). Classes of artefacts that are highly standardized, in both size and morphology, have also been identified to perform several functions, suggesting that even the most internally coherent types suffer from these same problems of use in multiple functions. ‘Projectile points’ have been noted to function as knives and be used on a wide range of materials (e.g. Moss 1983a; Neumann 1988), in addition to the more commonly argued role of hunting projectiles (e.g. Nuzhnyi 1990; Shea 1993). In contrast, other types, such as scrapers, have been found to differ
morphologically but function in the same way (e.g. Ahler 1971; Hester and Heizer 1973; Moss 1983a), indicating morphologically dissimilar functional equivalents may exist. Other analysts have identified multiple functions on the one tool (Semenov 1964; Moss 1983a; Vaughan 1985). Analysts who identify individual use zones by scanning the entire artefact for evidence of wear have identified up to five differently functioning use zones on the one artefact (Shen 2000 but see also Knudson 1973, 1978, 1979; Vaughan 1985; Knutsson et al. 1988; Shea 1988; van Gijn 1990; Shen 2000; Lemonier et al. 2006). Multiple use of the same tool has also been identified for barbs, backed blades and projectile points (Moss 1983a), with evidence that each of these forms have had secondary use in hide scraping activities (Moss 1983a; Vaughan 1985). Evidence of recycling has also been found with endscrapers, used blades and truncations recycled into burins for further use (Moss 1983a see also Neumann 1988; Shen 2000; Lemonier et al. 2006). Two important implications arise from the existence of recycled artefacts. The first is that, in some situations, tool users may be forced to use an artefact in a way that it is not primarily designed for, but circumstances are not conducive to producing the tool they would prefer. The second implication is that tool morphology was not entirely designed and that tool users had a more casual approach to tool use than typology supposes. This implies that tool morphology is much more fluid than analysts anticipate, with hunter-gatherers using any edge they believe will suffice for the task at hand, as has now been noted in several ethnographic studies (e.g. Wilmsen 1968; Gould et al. 1971; White and Thomas 1972; Hayden 1977; White et al. 1977; Deal and Hayden 1987). If this is the case then a wider range of morphologies may be capable of performing the same tasks than are predicted by typological classifications.

Studies that examine the edges of unretouched, as well as retouched flakes, have also noted the use of unretouched flakes in the full range of tasks for which retouched tools and formal ‘types’ were employed and are heavily supported by the ethnographic/ethnoarchaeological literature (e.g. White and Thomas 1972; Hayden 1977, 1979c; Grimes and Grimes 1985; Aldenderfer et al. 1989; Moore 2003; Shott and Sillitoe 2005). These results indicate that assertions of functional differences between retouched and unretouched flakes may be unfounded, with little or no functional difference detected between them (Fullagar 1986; Keeley 1980a; Keeley and Toth 1981; Moss 1983a; Sullivan and Rozen 1985; Shea 1988; Aldenderfer 1990; Hayden 1990; Grimaldi and Lemorini 1995; Lemorini et al. 2006).
Each of these results is a direct contradiction of the predictions of typological frameworks, suggesting that the relationship between form and function is not as unique as presumed. The existence of secondary use and recycling supports this theory by indicating that, for some functions, specific forms may not be necessary, with a wider range of forms able to suffice – even a fresh unretouched edge. This idea is discussed further below (see the 'Frison Effect' and Sequence Modeling). Retouch, therefore, does not seem to be uniquely associated with use (e.g. Hiscock 2004).

However, the extent to which these discrepancies between typological assumptions and functional ascriptions through wear-analyses refute typological ideas is dependent upon the validity and accuracy of the wear-analyses upon which they are based. In this, and the previous chapter, a number of problems have been highlighted associated with the identification and interpretations of artefact function, based on wear-analyses. Given that these problems are currently without solutions, there exist three possible causes of identified differences between artefact form and presumed function:

1. Limited understanding of the factors affecting wear and its relationship to use action and contact material means that interpretations of function based on wear-analyses cannot be trusted. If this is the case, typological frameworks remain untested, self-reinforcing hypotheses and have neither been supported or contradicted by wear-analyses.

2. Wear-analyses, though problematic and in need of extensive review, are capable of determining when one use is different from another, such that while specific materials or actions cannot be identified with certainty, differences in wear patterns are sufficient to infer that the cause of one type of wear is different to that of the other. If this is the case, typological systems are severely limiting and, in many cases, misleading, forcing new ideas of artefact morphology and function to be explored.

3. A final possibility is that form and function are, in fact, connected but at a different scale to that implied by typology. Two types may appear to be very different morphologically, but at the scale at which function operates, the relevant characteristics may be identical.

Our ability to determine which, if any, of these possible outcomes is correct is currently impeded by a crucial lack of knowledge in important areas of artefact function, artefact performance, its relationship with morphology and the ability to accurately identify artefact
function through wear patterns. Because archaeologists have failed to investigate the morphological characteristics contributing to artefact performance in relevant functions, we do not know the scale at which morphology and function interact. If function is the product of a particular combination of morphological features relevant to the working edge alone, then realistically, a wide range of variability in overall artefact morphology may still equate to functional equivalence. The archaeological test of notions of artefact function is the accurate identification of specific uses through wear and residue analyses. For these reasons, investigations into artefact performance and systematic experimentation of the generation and interpretation of wear patterns are essential.

The 'Frison effect' and Sequence Models

An ever increasing body of literature relating artefact morphology to technological processes of manufacture and maintenance, offers wear analysts a dynamic alternative to typological frameworks. The inspiration behind many of these investigations was the observation now known as the 'Frison effect' (Jelinek 1976). George Frison (1968) was one of the first (see Holmes 1893) to sequence the processes of edge rejuvenation and maintenance, using conjoin and refitting analyses on stone artefacts from the Piney Creek site, Wyoming. In contrast to the relationship between form and function dictated by typological classifications, Frison's observations revealed that maintenance activities lead to the continual modification of artefact form over time; such that the final form at discard may differ substantially from its original form. The significance of these observations resulted in the labeling of this phenomenon as the 'Frison effect' (Jelinek 1976). A number of important implications for stone artefact analyses arose from these observations, each of which is a contradiction of typological assumptions. The first of these relates to the ability of an artefact to assume several different forms in the sequence of events between artefact production and discard. This implied that, rather than being products of specific mental templates, much of the variation noted in archaeological assemblages may be accounted for by discard at different points along a continuum of morphological change brought about through the regular resharpening of tools (Frison 1968; Jelinek 1976). Secondly, the capacity for an original artefact form to differ substantially from its final form at discard invariably leads to questions about which, if any, of these forms represented the 'mental template' or the intended form of the knapper. The flow-on effect of being unable to determine which form was designed is the question of what artefact form, at discard, actually represents. In addition, the constant changing of forms implied that it was the specific functional edge, rather than the entire morphology of the artefact, that was relevant
to the knapper. Given that an artefact has exhibited many forms throughout its production history, as a result of being continually reshaped and reworked, it seemed likely that the features present at the point of discard were those that were considered no longer useful; that is, the artefact was discarded because it possessed the features the artisan did not want (Frison 1968; Jelinek 1976 see also Davidson 1991; Davidson and Noble 1993). Support for many of these ideas was immediately identified in the ethnographic and ethnoarchaeological literature. Observations had been made that tula and burren adzes represented repeatedly retouched forms (slugs) which when too small to be resharpened again are discarded (e.g. Gould et al. 1971; Hayden 1979), and others recorded the repeated resharpening and alteration of individual edges on the same implement for continued use (e.g. Tindale 1965; White and Thomas 1972; Gallagher 1977; Clark and Kurashina 1981).

Even greater support for these processes has been provided by an extensive and increasing body of literature specifically investigating the effects of maintenance activities on artefact morphology. The essential difference between this approach and more traditional typological concepts is the shift in emphasis from final and intended forms, to the processes involved in artefact manufacture and use (Hiscock 1993, 1994a; McPherron 1999). Lithic technologists have become increasingly convinced that much of the variation noted within archaeological assemblages was the product of artefact discard at ‘different points along a continuum of morphological change brought about largely through the effects of rejuvenation or reshaping of the tool edges’ (Dibble 1995:300, see also Villa 1983, Hiscock 1993, 1994a, 1988, 2003; Torrence 1984; Clarkson 2002a; McPherron 1995, 1999, 2000; Shott 1994, 1996a, 2003; Holdaway et al. 1996; however see also Close 1991 and reply by Dibble 1991; Bousman 1993). Sequence models (Bleed 2001), recording the sequence of production and maintenance events responsible for artefact manufacture and morphological variability between artefacts, have been conducted on lithics from, amongst others Australia (e.g. Hiscock and Veth 1981; Hiscock 1993, 1994a, 1988, 2003; Clarkson 2002a; Hiscock and Attenbrow 2002), Libya (e.g. Hiscock 1996b), south west Asia (e.g. Neeley and Barton 1994), Japan (e.g. Bleed 1996), Yugoslavia (Baumler 1988), North America (e.g. Goodyear 1974; Hoffman 1985; Morrow 1997), Israel (e.g. Marks and Volkman 1983; Gordon 1993; McPherron 2003), Egypt (e.g. van Peer 1992), Europe (e.g. Callow 1976; Bietta and Grimaldi 1990-1991) and in particular France (e.g. Villa 1983; Dibble 1984, 1987, 1995; Rolland and Dibble 1990; Kuhn 1992, 1995a; Holdaway et al. 1996). These models have been derived through replicative experimentation of implement production (e.g. Shott 1996a) and the tracing of use histories of archaeological specimens (e.g. Villa 1983; Bleed 1996; van Peer 1992; Holdaway et al. 1996; McPherron 1999;
Clarkson 2002a; Hiscock and Attenbrow 2002) via reduction indices (e.g Kuhn 1990; McPherron 1999; Clarkson 2002b; Hiscock and Clarkson 2005) or regression analysis (e.g. Shott 1996a; McPherron 1999, 2003). Further, three different approaches to sequence models currently exist (Bleed 2001): those that treat the sequence of reduction as a series of predetermined actions (Bleed’s 2001 ‘teleological’ models) such as the chaîne opératoire (e.g. Edmonds 1990; Boëda 1995; Inizan et al. 1999; McPherron 1995, 1999 see also Shott 2003); those that treat reduction as the product of situation and circumstance (Bleed’s 2001 ‘evolutionary models’ – e.g. Villa 1983; Dibble 1984, 1987, 1995; Hiscock 1994; Bleed 1996; Morrow 1997); and those that view reduction as ‘a continuous process of activities that blend seamlessly together’ (Bleed 2001:121 – e.g. Shott 1996a). While each of these differs subtly in approach, all sequence models emphasise understanding technological process as a means of understanding technological variability (Villa 1983; Dibble 1984, 1987, 1995; van Peer 1992; Hiscock 1993, 1994b, 1996a and b, 2006; Boëda 1995; Shott 1996a; Bisson 2000; Bleed 1996, 2001; Hiscock and Attenbrow 2002; Clarkson 2002a).

In identifying alternative sources of morphological variation, sequence modeling has allowed some technologists to utilise the approach to evaluate the validity of typological classes (e.g. Dibble 1984, 1987, 1995; Hiscock 1994b, 2006; McPherron 1995, 1999, 2000; Bleed 1996; Morrow 1995, 1997; Hiscock and Attenbrow 2002). Dibble’s (1984, 1987, 1995) models of Middle Palaeolithic scraper reduction continuums is one such example and illustrates circumstances in which a number of typologically defined classes, in fact, represent different stages of the one continuum. From the 22 types of sidescrapers identified in Bordes’ (1961) typology, Dibble (1995:318) identified four main classes based on the number of edges affected by retouch. Types that were differentiated on the basis of different edge shapes are grouped together, leaving the four main groups as single scrapers (retouch on one lateral edge), double scrapers (retouch two lateral edges), convergent scrapers (retouched edges meet at a point) and transverse scrapers (retouch on the broad edge of the distal end). Using two models of scraper reduction, separated on the basis of initial blank shape, Dibble argued that 22 of Bordes’ (1961) types can be hypothesised to represent points along maintenance and rejuvenation based reduction continuums. The single-double-convergent model predicts that retouch begins along one side of a scraper and produces a single scraper, while use and rejuvenation of a second edge will result in a double scraper. The continued use and rejuvenation of both, or one side, may eventually result in their meeting and generating a convergent scraper. In the single-transverse model the original edge used continues to be rejuvenated and used with resharpening episodes, gradually changing the axis of retouch and eventually resulting in a transverse scraper.
Use-Wear in Archaeological Interpretation

Chapter 3

A similar model has been developed by Hiscock and Attenbrow (2002) to describe scraper-reduction sequences at Australia’s Capertree 3 site. Using Kuhn’s (1990) reduction index to trace the manufacturing history of the artefacts present, Hiscock and Attenbrow (2002) identified a single continuum of reduction, linking four of McCarthy’s (1964) original scraper types: ‘side or end,’ ‘side and end,’ ‘double sided’ and ‘double sided and end’ scraper, in which ‘extent of reduction explains more than 74% of variation in shape of the retouched edge’ (Hiscock and Attenbrow 2002:171). Villa (1983) also recorded procedural connections between types at the Terra Amata site in Southern France, observing that ‘Through a decrease in the degree of symmetry and elongation, the Terra Amata picks merge imperceptibly into regular choppers. Through decreases in the length of the working edge and in size, they merge into becs; through an increase in denticulation and, ultimately a change in kind of blank (from pebble to flake), they merge into Tayac points’ (Villa 1983:119). Similar reduction sequences have now been identified for a number of artefact types, including Pleistocene ‘Dalton Points’ (Goodyear 1974), North American and Australian projectile point typologies (Ahler 1971; Hoffman 1985; Hiscock 1994b; Flenniken and Raymond 1986), bifacial handaxes (Jones 1994; McPherron 1995, 1999), backed artefacts (Hiscock and Attenbrow 2002, 2003, 2004), notched tools (Holdaway et al. 1996), fluted bifaces (Shott 1996a), microblade cores (Bleed 1996, 2002) and additional scraper types (e.g. Shott 1995; Morrow 1997; Clarkson 2002a, 2005). The identification of sequence models, over several continents and covering a wide range of time periods, indicates that these sorts of processes were neither spatially, nor temporally, constrained and make an invaluable contribution to the interpretation of artefact assemblages worldwide.

In most cases, the type of each class of artefact represented is argued to be subject to the amount of reduction the artefact has sustained, with some types represented by earlier stages of reduction and others by more intensively reduced forms (e.g. Goodyear 1974; Jelinek 1976; Villa 1983; Baulmer 1988; Hiscock 1994b; Dibble 1984, 1987, 1995; Hoffman 1985; Flenniken and Raymond 1986; Holdaway et al. 1996; Hiscock and Attenbrow 2002). For example, in Hiscock and Attenbrow’s (2002) model, ‘side or end’ scrapers represent the earliest stages of reduction while ‘double ended and side’ scrapers are the more heavily reduced forms. However, the degree to which any artefact is capable of being reduced will be dependent upon the original size and quality of the raw material utilized (Kuhn 1995b; Brantingham et al. 2000). Assuming that artefacts are discarded, or less effective beyond a certain size threshold, artefacts manufactured on larger blanks will be capable of sustaining much higher levels of retouch than will smaller blanks before being discarded (Kuhn 1992;
Hiscock 1982, 1994b; Dibble 1995; Hiscock and Attenbrow 2002). Likewise, the extent of reduction possible will be dependent upon the qualities of the raw material utilised, with the fracture paths of heavily flawed materials being particularly difficult to control (Goodyear 1989; Brantingham et al. 2000). Any reduction process is therefore necessarily dependent upon the quality and size of the blanks manufactured for use, while different shaped blanks will give rise to different reduction processes (e.g. Villa 1983; van Peer 1992; Bleed 1996; Inizan 1999; McPherron 1999; see also Frison 1968:150). In each case, however, reduction is focused upon maintaining the longest edge possible for as long as possible. A final implication of the ‘Frison effect’ for typological analyses is therefore that far from indicating the attainment of an ideal form imbued with social meaning, retouch may simply represent the means by which the knapper may make a tool functional or maintain a functional edge. As such, sequence models differ considerably from traditional typological ideas, focusing on individual edges as the functional goal. Indeed, double and convergent scrapers are assumed to be ‘the same as a single scraper – a tool with only a single edge being utilised at any one time’ (Dibble 1995:322). Many traditional ‘types’ are therefore explainable in terms of multiple functional edges occurring, in association with one another, rather than as a single functional entity.

Functional Implications of Sequence Models

The idea of artefact morphology as the product of multiple changes due to use and maintenance activities has a number of important implications for artefact function; implications that have rarely been addressed by proponents of sequence models. The focus upon individual edges as functional components implies that the features that are important to artefact function, in whatever capacity, occur on these edges. Yet, despite the discovery that artefact morphologies are constantly changing through processes of rejuvenation, little thought has been given to the effect of these changes to functional requirements.

Central to these models is the concept that retouch and rejuvenation has the potential to drastically alter the original shape of an artefact. The effect of rejuvenation on artefact morphology depends on the reductive processes applied. Some of these are illustrated in Figure 3 which details the effects of unifacial and bifacial reduction on edge shape and angle. Unifacial reduction results in an increase in edge-angle, while certain types of bifacial reduction can occur without this change in edge morphology (e.g. Solberger 1971; Kelly 1988; Hayden 1989; Hiscock 2006). However, where there is a directional change in
morphology, each rejuvenation event changes the working edge in terms of the features it possesses: plan, profile, edge-angle and the size and nature of the contact points along the edge. These changes in form suggest two outcomes for artefact function and are illustrated in Figure 4:

1. Changes to edge morphology, relative to angle and shape, have little to no effect on the edge’s ability to function, enabling the edge to continue with its initial task. In this case, retouch would simply maintain the edge’s original performance levels. Subject to the scale of alteration imposed upon the edge by retouch, this outcome implies that a wide range of edge features will be equally capable of performing the same function and suggests that differences in edge morphologies may be only partly explained by differences in function.

2. Changes to the shape and size of the functional edge by retouch serve to resharpen the edge with varying outcomes on its ongoing productivity. If changes in morphology, through retouch, are directional, then these changes may either enhance or decrease artefact productivity. If change is towards an increasingly
unsuitable form then effectiveness may decrease, while change towards an increasingly suitable form suggests effectiveness may be enhanced. This hypothesis predicts that differences in the size, shape and angle of the working edge affect the performance of that edge in a given task. The implication is that different combinations of morphological features may be better suited to performing particular tasks than are others. If this is the case, some directional changes in morphology may be sufficient to cause a shift in the function for which a tool may be best suited. That is to say that if edge reworking is intensive it may be sufficient to change the function of the artefact entirely, allowing it to be recycled and applied to a different task.

The first of these, which suggests that changes in edge morphology through retouch do not affect the artefact’s ability to perform a particular function, implies that edge morphology has no effect on artefact performance (see figure 4a). If this is the case, archaeologists should not expect to find correlations between artefact or edge morphologies and particular functions and greater merit should be given to alternative explanations of artefact morphology. However, the archaeological test of this model requires the ability to either accurately identify the functions of archaeological artefacts or to quantify the performance of different edge morphologies in order to determine the effects of changing morphology.

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![Figure 4. Predictive models of changing performance levels and functions with progressive edge rejuvenation events.](image)

(a) Retouch does not decrease implement effectiveness, resulting in complete rejuvenation of the edge to the same levels of effectiveness as unretouched or previously retouched edges. Retouching events will continue to return the edge to maximum effectiveness until the implement breaks or until lack of material prohibits further reduction.

(b) Retouch alters the function for which the edge is now most productive by changing important qualities of the working edge. One reduction episode may diminish the edges performance in cutting meat, but in doing so may create the ideal edge for scraping wood. A second rejuvenation episode may change the edge again such that the combination of features produced is an extremely high performer at cutting bone, and so on. The knapper may therefore choose to continue cutting meat at a much reduced capacity, or use the artefact in a different function in which it will attain higher performance levels.
on the ability of the edge to perform different tasks. The accurate identification of the presence, or absence, of correlations between edge morphologies and function or quantification of the effects of various morphological features on edge performance would provide sufficient information to support or reject this hypothesis.

The second hypothesis suggests that edge morphology and function are sufficiently related to allow continued retouch to either diminish or enhance edge effectiveness (see figure 4b). This implies that some relationship exists between edge morphology and artefact function. However, the extent to which functions may be indicated by morphology is dependent upon how much morphological variation is required before performance levels change. For example, it may be that, in some activities, a large range of edge-angles or shapes will result in very similar performance levels, while in other activities only minimal variation may be possible before performance is compromised. In order to test these ideas, it is again necessary to quantify the relationship between edge features including size, shape and angle on the productivity of the edge. Maximum and minimum values for features such as edge-angle and size need to be established which define the ranges in morphological variation that are possible before compromises result in edge performance, for each function. Having identified these thresholds, it should then be possible to determine the likelihood that an artefact may be recycled over time. The extent of recycling likely to occur will be dependent upon how much morphological change the edge can sustain before it is no longer suitable for its previous function and is more suited to another. Subject to the amount of change necessary to induce recycling behaviour it may be possible for a single artefact to be involved in multiple and entirely different tasks over the course of its use-life, depending on the particular features the functional edge possess after each retouch episode. Use-wear evidence could also provide support for, or refute, these ideas. Given that the form of an artefact recovered from a site represents its final form before discard, the functions evidenced on artefact edges are also likely to indicate only the most recent functions; that is, those functions that occurred between the last retouch episode and discard. However, in accordance with Dibble's (1995) reduction hypothesis, we would expect that if edge morphology can be shown to have some effect on performance levels, then artefacts discarded at the same stage of reduction, or bearing the same morphological edge features, would show evidence of having performed similar functions at this final stage of use.

At present, lithic analysts have no means of testing the degree to which either of these models describes the nature of artefact use in prehistoric assemblages. The scale at which
rejuvenation takes place may be an important factor and, in some cases, it may be insufficient to cause dramatic changes to the edge, while in others it might be extensive enough to result in one of the changes suggested above. However, typologists and technologists utilising sequence models have failed to explore the crucial relationship between artefact morphology and function, or the implications of their hypotheses upon these aspects of technological use. In the absence of this knowledge, it is impossible to know what effect, if any, changes to the shape of the working edge through maintenance activities have on the ability of an artefact to perform the function asked of it. As such, it is impossible to know whether knappers would be better served by continuing to use the edge in the same task, simply resharpening the edge where necessary, or to consistently use particular edges for one task and, when retouch changes those edges beyond a certain point where productivity declines, appoint the edge a different task to which it will be better suited. Such problems again highlight the need for a targeted study of artefact performance in order to better understand the relationship between changing morphology and functionality.

**Sequence Models and Wear-analyses**

Compounding these problems is the effect that edge rejuvenation has on the development and interpretation of use-wear. In addition to problems associated with the removal of use-wear by retouching the used portion of the edge, use-wear analysts must cope with the effects these changes to the edge may have on the development of future wear. While the previous chapter highlighted the fact that, to date, very little is known of the effect of edge morphology on the generation of wear, it has been noted that low edge-angles incur much greater frequencies of scars than do high edge-angles (e.g. Tringham et al. 1974; Odell 1980; Kamminga 1982; Moss 1983a; Tomenchuk 1988). Low edge-angles are also found to sustain higher incidences of bending initiations and feather terminations than are high edge-angles, which experience greater numbers of hertzian initiations and stepped or hinge terminations. Using edge-angle as an example, it is clear that changes to the edge through rejuvenation, accompanied by an increase in edge-angle, will result in the generation of an entirely different wear pattern to that developed on the previous edge, even if it continues to be used in an identical function. This implies that it is not only variation in function that contributes to the development of wear, but the morphology of the functional edge also. This has the potential to greatly complicate the identification of artefact function through wear. If it is discovered that artefact performance and morphology are connected and
morphology and wear are connected, then how do we interpret assemblage variation in wear? If differences in raw material, edge-shape, edge-profile, edge-angle, retouch and so on each contribute in some way or other to the types and frequencies of wear generated during use, in addition to those caused specifically by function, each of these must be taken into consideration when drawing comparisons between the functional compositions of different assemblages. Compounding these problems is the possibility that different edge morphologies may be capable of performing the same function. This means that the function may be represented in an assemblage by very different edge morphologies, each of which will manifest wear characteristics quite differently in accordance with its edge-profile, plan, edge-angle and so on.

At present, wear analysts assert functional differences within, or between, sites on the basis of the proportions of the particular types present (e.g. Lewenstein 1981; Aldenderfer 1990; Knutsson 1990; Caneva et al. 1996; Kealhofer et al. 1999; Shen 2000). However, from the discussion presented in the last two chapters it is possible that the use of different raw materials, accompanied by subtle differences in the morphological characteristics of the functional edge and not the entire artefact, will result in different manifestations of wear from use. It is therefore foreseeable that, rather than representing different functions and activities at a site, artefact variability does not reflect difference in function but simply tools performing the same functions at different stages of reduction. The discovery that one function may be represented by a wide range of artefact morphologies and combinations of wear types would have enormous implications for the interpretation of archaeological assemblages. Such results would be in direct conflict with almost every assumption upon which traditional typological frameworks are based, implying that many interpretations constructed upon them may be unfounded. The implications of such a discovery on the interpretation of archaeological assemblages would be far-reaching.

CONCLUSIONS

The discussion in this chapter highlighted a widespread dependence upon a number of largely untested assumptions relating artefact form to function. The current dependence upon typological frameworks to guide wear-analyses at multiple stages of use, including the construction of experiments, selection of artefacts for analyses, location of wear and interpretation of sites has limited the interpretive power of analyses, unnecessarily narrowed its focus and falsely reinforced typological concepts. While promising alternative approaches to normative typological models exist, these too are based upon untested
assumptions. The widespread failure of analysts and technologists to identify and investigate the crucial relationship between artefact morphology and performance means that, at present, we are unable to test or expand upon current theories with any certainty. These shortcomings reveal a clear need for targeted and systematic studies into artefact performance. In addition, improvement in the accurate identification and interpretation of wear generated by artefact use must be regarded as essential if we are ever to interpret prehistoric stone artefact assemblages with any certainty. At present, poorly determined functional ascriptions are being used to construct interpretations of the past that are based upon untested, and at present, untestable, assumptions.

This chapter represents a crucial step in illustrating the way in which current interpretations of artefact function have been used to generate an understanding of the past. The previous chapter explored identification of function at the level of individual artefacts, while this chapter outlined how these identifications are then used to construct larger scale theories of spatial and temporal difference in site function, using individual or groups of artefacts. The following chapter explores these same ideas but on a much larger scale, exploring how notions of functionality relate to the construction and development of synthetic concepts of whole technological systems which are currently used to explain major differences in assemblage variability over large areas or covering extensive periods of time.
CHAPTER 4

THE ORGANISATION OF TECHNOLOGY AND ARTEFACT FUNCTION

INTRODUCTION

This chapter characterises notions of artefact function as they relate to broad scale behavioural theories of hunter-gatherer subsistence. In contrast to the direct functional interpretations derived by wear-analyses, models that examine technology as a crucial means of maximising efficiency in subsistence practice assume that artefacts not only performed individual functions, but also, at a higher level, functioned to enable hunter-gatherers to exploit their environment with greater ease. These models have been labelled the 'organisation of technology' (Kelly 1988), 'design considerations' (Nelson 1991) or 'provisioning systems' (Kuhn 1994) and explore the manufacture and use of stone artefacts as technological plans which are argued to be responsive to ecological and behavioural constraints on subsistence. However, while providing archaeologists with innovative approaches to interpreting prehistoric technologies these models are based upon a number of untested assumptions about artefact function and functional efficiency. A general failure to define what is meant by the term 'tool,' or to understand the physical and functional limitations notions of toolness place on artefact morphology, means that technologists are currently unable to test their own theories or to identify them archaeologically. These difficulties are explained in the following pages.

THE DEVELOPMENT AND CONCEPTS OF ORGANISATION OF TECHNOLOGY MODELS.

The idea that technological strategies could change and adapt according to differences in social or environmental constraints was developed primarily in the United States, as the product of attempts to articulate technology and settlement (e.g. Binford 1968, 1977, 1979, 1980). Increasing interpretive value and attention was focussed on these ideas throughout the 1980's with a generation of archaeologists including Torrence (1983, 1984, 1989b), Bamforth (1985, 1986), Bleed (1986) and Kelly (Parry and Kelly 1987; Kelly 1988; Kelly and Todd 1988) exploring concepts of tool design and manufacture and their implications for subsistence practice. Since their inception, these ideas have gathered momentum,

The term ‘organisation of technology’ has been defined as

‘...the spatial and temporal juxtaposition of the manufacture of different tools within a cultural system, their use, reuse and discard and their relation not only to tool function and raw material type and distribution, but also to the behavioural variables which mediate the spatial and temporal relations among activity, manufacturing and raw material loci...’ (Kelly 1988:717).

The approach identifies circumstances for artefact manufacture and use that extend beyond strict functional requirements. Stone artefacts are considered technological solutions to a wide range of situationally conditioned problems (Torrence 1980, 1983, 1989b; Jeske 1989; Bousman 1993; Hiscock 1994a, 2005; Wallace and Shea 2006) with tool design, staging of manufacture, use and reuse all considered to be responsive to resource conditions (Nelson 1991:57). As such, relevant social, economic and environmental conditions are argued to be reflected in the technological strategies designed to negotiate them.

Technological organisation models are based on the economic premise of cost to benefit, assuming that humans will consistently seek to maximise benefit relative to cost in any situation (Hayden 1977, 1989; Torrence 1983, 1984, 1989; Bamforth 1986; Parry and Kelly 1987; Kelly 1988; Boydston 1989; Jeske 1989; Jochim 1989; Lurie 1989; Bousman 1993; Hiscock 1994a; Fitzhugh 2001; Bamforth and Bleed 1997; Milliken 1998; Wallace and Shea 2006). Technology is seen to improve subsistence efficiency 'by reducing input in terms of energy, time and risk, or by increasing output' (Lurie 1989:46 see also Torrence 1983, 1989b; Jeske 1989, 1992). The theory of optimisation assumes that decision makers have some knowledge of the performance characteristics and abilities of known technological solutions. As such, it is expected that, where possible, hunter-gatherers will choose to utilise that set of solutions known to produce the highest rate of return for time and energy invested (Torrence 1983; 1989b; Bleed 1986; Jeske 1992; Bousman 1993; Bamforth and
Bleed 1997; Milliken 1998; Brantingham et al. 2000; Fitzhugh 2001. Problems in this context are identified as 'obstacles to achieving maximum return on investments of time and energy' (Nelson 1991:60 see also Smith 1979:55; Torrence 1983; Bleed 1986:738) and include conditions of time-stress (Gamble 1986; Smith 1979; Torrence 1983), energy cost (Bleed 1986; Bleed and Bleed 1987), mobility requirements (Binford 1978, 1979; Kelly 1988; Kelly and Todd 1988; Shott 1986), raw material availability (Bamforth 1986; Kelly 1988; Brantingham et al. 2000), raw material quality (Andrefsky 1994; Goodyear 1989) and risk management (Torrence 1989b; Hiscock 1994a). Technological strategies will therefore always differ, in response to changing circumstances between humans and their environment and may improve cost/benefit ratios either by increasing net returns or by reducing the time/energy required to procure resources (Bousman 1993). Accordingly, differing technological strategies result in variable artefact morphologies which are argued to be identifiable, archaeologically, on the basis of assemblage composition and diversity.

Nelson (1991) identifies three broad technological strategies which are adopted, to varying degrees, by hunter-gatherers relative to circumstance. Artefact form and assemblage composition will be direct consequences of these differing strategies of tool use, opportunism, expediency and curation. Opportunism will occur in response to immediate, but unanticipated, needs (Binford 1973, 1977, 1979; Nelson 1991). It is entirely unplanned behaviour in which knappers exploit unanticipated resources to furnish unanticipated needs and is therefore conditioned by circumstance. By comparison, expediency 'refers to minimised technological effort under conditions where time and place of use are highly predictable' (Nelson 1991:64). As such, expedient strategies are argued to occur when hunter-gatherers anticipate the presence of suitable raw materials at use locations and where there are no time constraints on the manufacture and use of artefacts (Binford 1973, 1977, 1979). They therefore tend to be used for only short periods or for single uses and are rarely retouched, being manufactured, used and discarded in accordance with immediate needs. Curation, however, anticipates a need for materials and tools at various locations. The term has been used and defined in many ways and encompasses a complex of technological behaviour involving the scheduling of artefact production in advance of use, transport of artefacts from location to location, maintenance and reshaping of tools, and caching, or storage, of artefacts for use at various locations (Binford 1973, 1977, 1979; Bamforth 1985, 1986; Nelson 1991; Bousman 1993 see also Shott 1996b; Shott and Sillitoe 2005). Curation serves to maximise efficient use of time, energy and resources by bridging differences in circumstance between availability of raw materials or tools and the time, and location of tool-use activities (Binford 1973, 1979; Bamforth 1986; Parry and Kelly 1987;
Curated artefacts tend to be heavily retouched in an effort to conserve available materials for localities where raw material, time and energy constraints exist in tool-using localities. Curation and expediency therefore represent scheduling alternatives particular to different circumstances.

Curation has often been argued to be enabled by the existence of a number of design systems that are capable of maximising, or minimising, various organisational attributes in accordance with situation (e.g. Bleed 1986; Nelson 1991; Bousman 1993; Shott 1995, 1996b; Hiscock 2006). Design systems seek to maximise one, or more, of four qualities considered to be advantageous: reliability, maintainability, flexibility and versatility. While originally conceived of as an explanation of design variability in hunting weaponry only, Bleed's (1986) seminal paper differentiating maintainable and reliable design systems has since been broadened to include other aspects of lithic technologies, with the view that the pressures acting upon extractive weapons are equally able to 'stimulate specific changes in technological replacement and maintenance strategies' (Bousman 1993:77 e.g. Hiscock 2006). Reliable systems are designed to function at some level, regardless of circumstance. These should be well maintained, break down rarely, if ever, and are designed to continue to function in some capacity if break-downs do occur (Torrence 1983; Bleed 1986; Myers 1989; Nelson 1991; Eerkens 1998). Reliable systems are argued to be symptomatic of situations in which the chance of failure to procure a specific resource is high. It is therefore generally believed that, in order to ensure the successful procurement of particular resources, reliable tools tend to also be specialised, manufactured with features that enhance the likelihood of procuring a specific resource (e.g. Torrence 1989; Lurie 1989). It is generally assumed, in discussions of reliability, that no one tool will be capable of reliably performing a wide range of tasks. Maintainable systems, however, are argued to be simpler than reliable systems (Bleed 1986; Myers 1989; Eerkens 1998), enabling them to readily and quickly repaired and produced and to work easily under a variety of circumstances. If not immediately suitable for a task, maintainable artefacts may be quickly and easily made to function. If damage occurs to maintainable implements they are designed to continue to function at a lower capacity and should be easily repairable. As such, maintainable systems are thought to be generalised, able to perform a wide range of tasks under different circumstances but, at lower performance levels than would more specialised alternatives. Within maintainable systems artefacts may be manufactured to include strategies of flexibility or versatility: 'those which are changed in form to achieve multifunctional demands (flexible) and those which are maintained in a generalised form to meet a variety of needs (versatile)' (Nelson 1991:70). A flexible tool can be easily reshaped to meet a variety of
needs. For example, bifaces are often cited as flexible designs (Kelly 1988; Nelson 1991; Bousman 1993; Ashton and McNabb 1994), being able to take on a number of forms throughout their reduction sequence. Comparatively, versatile designs can perform a wide range of tasks without changing form. The advantage of having flexible or versatile designs is the wide range of tool-use potential that they supply for the same costs as maintainable systems. Both reliability and maintainability are attributes considered desirable in provisioning models, such that, where possible, the knapper is expected to maximise both (Eerkens 1998; Bleed 2002). However, where circumstances prohibit the maximisation of both it is expected that one of these attributes may be compromised to enable increased gains in another.

Each of these technological strategies and associated design systems is considered in greater detail in the following discussion which outlines the ideal circumstances under which each would operate. However, it is necessary at this point to highlight the fact that critiques of this literature are rare, with research tending to be built upon provisioning concepts without prior evaluation of their implications for artefact function or their ability to be identified in archaeological contexts. Despite the explanatory power of many of these concepts, they are not without problems. Models of provisioning systems and technological strategies make a number of assumptions about artefact function which are currently untested. Primarily, these models assume that hunter-gatherers will always have access to the right tool to fulfil any function, at the right time. In forwarding these concepts, researchers have assumed that it is possible to maximise qualities such as flexibility and versatility without affecting the ability of these artefacts to perform the specific functions required of them, such as scraping or sawing and so on. The implication is that any number of changes may be imposed upon tool morphology without compromising function, with functional efficiency assumed to remain constant. In reality, archaeologists are currently unaware of exactly which morphological components of an artefact or functional edge contributes to its efficiency; moreover the effects of maximising different technological qualities on the performances of individual artefacts are unknown. Essentially, models of technological organisation have explored technological efficiency in a void of information regarding performance or efficiency at the level of individual artefacts. Yet efficiency at the scale of artefact or activity must be recognised as having a critical effect on technological efficiency at a broader level (Bamforth 1986; Bousman 1993). Further problems include the failure of technological organisation models to consider limitations that may be placed on artefact form or function through features of manufacture which are widely acknowledged to influence process of reduction and the final
morphology of the artefact at discard, such as blank morphology (Hiscock 1982; Villa 1983; van Peer 1992; Dibble 1995; Bleed 1996; Inizan 1999; McPherron 1999 see also Frison 1968:150 Dibble and Pekin 1995). A final assumption is that differences in design strategy are recognisable archaeologically; that each strategy is represented by unique and identifiable morphological differences. However, in the absence of any understanding of what constitutes an effective edge in the performance of specific tasks, it is unclear how archaeologists are to recognise and differentiate between forms that are particularly suited to one, or other, task or to perform within specific design strategies. As a consequence, models of technological organisation have yet to be independently verified in an archaeological context, being dependent upon an understanding of the relationship between artefact morphology and performance that is, as yet, unknown.

**OPTIMISING VARIABLES THROUGH TECHNOLOGY**

In selecting between various technological solutions, it is assumed that humans will attempt to balance competing goals and maximise others in order to derive toolkits appropriate to the situation (Torrence 1983, 1984, 1989b; Bousman 1993; Hiscock 1994a; Fitzhugh 2001; Bamforth and Bleed 1997; Milliken 1998; Wallace and Shea 2006). Time and energy are the primary currencies assumed to be managed and optimised by hunter-gatherers, both being imperative to the survival of all populations and yet constrained, in some way or another, by the economic environment in which they exist (Torrence 1983, 1984, 1989b; Jeske 1992; Fitzhugh 2001; Bright et al. 2002; Ugan et al. 2003). While some models emphasise time and energy as independent causes of variability (e.g. Torrence 1983, 1984, 1989; Jeske 1989), others use time and energy as currencies, measuring the success of different technological strategies relative to their ability to maximise cost to benefit ratios in time and/or energy-expenditure (e.g. Binford 1973, 1979; Hiscock 1984, 1996a; Kelly 1983, 1992; Shott 1986, 1990; Parry and Kelly 1987; Lurie 1989; Andreffsky 1991; Kuhn 1994; Morrow 1997; Cowan 1999; Wallace and Shea 2006). Models exploring technological organisation have identified a number of different aspects of subsistence practice that include time-stress, energy-expenditure, risk reduction needs, mobility requirements and limitations on raw material quality and availability, each of which are believed to be reflected in the archaeological record by variation and diversity in assemblage composition. Each of these strategies has a number of implications for artefact function and is discussed below.
Energy, Time and Risk

The interrelationship between time and energy makes them difficult to separate and, in many cases, discussions of hunter-gatherer behavioural efficiency combine the effects of both of these currencies (e.g. Jeske 1989; Lurie 1989). Energetic efficiency can be measured in relation to energy use (e.g. Bleed and Bleed 1987) or energy-capture relative to time invested in that pursuit (e.g. Jeske 1992). Increases in energy-capture are likely to create relative abundance in time by reducing the amount of time required to capture resources. The same may be said in reverse, whereby energy-stresses create the need to spend more time on energy-capture, resulting in an associated time-stress. Nevertheless, it is generally believed that, in certain situations, hunter-gatherers will have needed to emphasise one more than the others with different outcomes on technological strategy.

Humans are argued to optimise energy based on the premise that, all else being equal, organisms that are efficient in energy-capture and use will have greater reproductive success than those that are less efficient (Torrence 1983, 1989b; Jeske 1992). Two separate responses to constraints on energy are predicted; efforts will be made to either maximise energy-capture or minimise energy-expenditure (Jeske 1992). The first premise dictates that where energy is stressed, greater effort will be put into the manufacture of technologies, in order to either conserve available material or to increase the energy yield from the environment. The conservation of available material reduces energy-expenditure by relieving the frequency with which raw material must be procured (Hayden 1989; Hiscock 1994a). Where energy and raw materials are at a minimum, processes of reduction which minimise the need to procure more materials are predicted, as are reduction in the size of tools, adoption of reduction processes which obtain greatest cutting edge from available material and decreased frequency in replacement tools (Hayden 1989:10). Where greater effort is expended in the improvement of technology, it is argued that technologies will become more specialised and reliable in order to increase the likelihood of procuring high energy resources and minimise the effort required. By increasing the proficiency with which resources are procured, highly curated and specialised forms must therefore maximise energy returns (Torrence 1983, 1989a; Jeske 1989; Lurie 1989; Myers 1989). The second possible outcome of energy-stress is energy-conservation through the reduction of energy-expenditure. The fact that there are inevitable limitations on energy availability within a group means that increases in energy requirements in one area of society will invariably mean removing or decreasing energy investment in other aspects of subsistence, if increasing energy-capture becomes maladaptive. Energy costs in tool manufacture can
be reduced by a number of technological methods if energy is needed elsewhere (Jeske 1992). Bipolar reduction has been cited as one technological outcome of efforts to reduce energy-expenditure (Jeske 1992), allowing knappers to extend the usability of available material by enabling cores to be reduced further than is possible by other reduction techniques. The need to expend energy in the procurement of new raw materials thereby decreases with greater utility of available materials.

Time allocation models are based upon the belief that hunter-gatherers have a finite period of time during which to undertake the tasks necessary for survival, each of which is related to a number of costs and benefits (Bousman 1993). Limitations in the time available to complete particular tasks are seen to directly impact upon technological choices. As such, differences in the degree and severity of time-stress experienced by a group will lead to associated differences in the technological strategies adopted by that group (Torrence 1983:12). The costs associated with time-stress are argued to be obviated through technology by adopting behaviours that either minimise the time spent in tool manufacture and maintenance or maximise the net return of resources through technology (Bousman 1993; Bright et al. 2002; Ugan et al. 2003). Investigations into the investment of time in the improvement of technology indicate that certain thresholds may exist, beyond which increased investments of time are not cost-efficient and output no longer proportionate to input (Ugan et al. 2003). This means that, 'under many circumstances, smaller and smaller gains in performance come at an increasingly greater cost' (Ugan et al. 2003:1316). As such, the net returns provided by any technology must be sufficient to justify the initial time required to establish and manufacture the system (see also Bettinger et al. 2006).

Reliable and maintainable systems were initially presented as a means of optimising time at various stages in artefact manufacture and use in response to time-stress (Bleed 1986; Myers 1989; Torrence 1989). Seasonal availability of important subsistence resources or the need to capture prey, during the finite period that the opportunity presents itself is argued to create time-stress on activity performance (Bleed 1986; Torrence 1989). The 'amount of time a system has available to do its job' (Bleed 1986:739) is argued to be optimized by one or other of two technological strategies: reliable or maintainable technologies (Bleed 1986). The degree to which either system is built into a technology is dependent upon the time available to complete each task (Bleed 1986). Reliable systems are therefore argued to be more important where the cost of failure to procure a resource is high and where the time available to do so is limited, such as in capturing prey. In these cases, it is imperative that the technological system works when it is needed. As such,
reliable systems tend to be part of a technological adjustment to unpredictable, or seasonal, resources and are considered to represent technological specialisation (Torrence 1989). In contrast, maintainable systems are most appropriate 'for generalised undertakings that have continuous need but unpredictable schedules and generally low failure costs' (Bleed 1986:741). These implements are ideal for the procurement of regularly available resources and for the fulfilment of activities that are not time-stressed (Torrence 1983). Efforts to maximise available time through the development of more efficient tools are argued to be reflected in assemblage structure and measured according to composition of functional types, diversity of tool types and the complexity of individual tools (Torrence 1983).

Technology is seen to reduce the severity of risk imposed on hunter-gatherer groups in a number of ways (Torrence 1989; Myers 1989; Hiscock 1994a; Bleed 1996; Bamforth and Bleed 1997; Fitzhugh 2001). Risk 'is defined as the probability of economic loss' (Bousman 1993:64) and arises where resource availability is limited through the seasonal availability of resources (Kelly and Todd 1988; Torrence 1989; Myers 1989; Shea 1993), environmental change (e.g. Hiscock 1994a, 2002), high mobility, unfamiliarity with resources and a dependence upon mobile prey (Kelly and Todd 1988; Myers 1989; Shea 1993). The severity of risk is therefore argued to be determined by the severity of the consequences of losing that resource (Torrence 1983; Bamforth and Bleed 1997; Fitzhugh 2001). Risk is measured by uncertainty in resource availability which means that often it is 'monitored through the use and availability of time' (Myers 1985:59). However, in risk reduction theories time is not minimised for its own sake but because resource availability affects capture rates; that is, it affects the nature and severity of risk.

'The necessity for increasing the speed of capture and for budgeting limited time is created by the type and severity of risk. Consequently, the ultimate cause for the nature of tool-kits observed is not time but potential risk' (Torrence 1989b:60).

Hunter-gatherer selection of design systems and technological strategy will depend on the nature and severity of the risk involved. The more important a resource is to subsistence, the more effort will be invested in the manufacture of a technology for exploiting it (e.g. Torrence 1989; Bousman 1993; Ugan et al. 2003), in an effort to minimise loss of that resource. Reliable, and therefore specialised designs, are expected in areas of high risk, while maintainable and generalised design systems are better suited to low risk circumstances, on the grounds that 'tools designed to perform specific tasks should be
more efficient in the performance of those tasks than tools designed for a broader range of tasks' (Myers 1989:87). However, in some cases the advantages of building both reliability and maintainability into the technological strategy, or switching between the two as required, has also been recognised (Shea 1993; Myers 1989). Alternatively, the manufacture of maintainable, portable and multifunctional design systems has been forwarded as a second means of reducing risk (Bousman 1993; Hiscock 1994a, 2002), by increasing 'the readiness' of the toolkit and therefore to reduce subsistence risk' (Hiscock 2002:168). Further, it is possible that, in some cases, the time invested in the production of tools removes time from other activities. As such, time and energy may only be channelled into the design and manufacture of complex designs and systems if it is possible to take that time and energy away from other activities without incurring great costs in terms of either of these qualities. Optimality may therefore not always be possible, despite an awareness of the properties required (Bamforth and Bleed 1997). Circumstances have therefore been identified under which both maintainable, and reliable, design systems are predicted to reduce subsistence risk.

Abundance strategies have also been presented as potential outcomes of increased resource risk (Hiscock 2006, see also Kuhn 1995a), by prolonging the efficiency of limited raw materials at hand. In addition, or as an alternative to extending the useability of artefacts through the rejuvenation of an edge, risk-reductive behaviour could include high production rates of small, standardised items that have a lower potential for reduction but which can exist in larger numbers, utilising the same amounts of raw material (Hiscock 2006:83 also Jeske 1989). This strategy 'is one that yields fresh tools rather than maintaining existing ones, given an equal consumption of raw material' (Hiscock 2006:85) and is therefore presented as a technology that is suited to circumstances relating to high risk, as well as high raw material procurement costs.

The amount of technological adjustment and innovation that hunter-gatherers will make is also argued to depend upon the strategies they use to cope with risk, whether they are risk-averse or risk-prone (Bamforth and Bleed 1997; Fitzhugh 2001). Hunter-gatherers practicing risk aversion strategies will seek to reduce variance by increasing the predictability of the outcome. Conversely, risk-prone hunter-gatherers pursue solutions with high variance on the off-chance that high returns will result. The model predicts that where risk-prone strategies tend to pay off and where greater returns are yielded from investments, hunter-gatherers will be more likely to be innovative and produce new forms. When risk-averse strategies are used there is more to be lost than gained and technological
behaviour will be conservative, focusing on those techniques already tried and tested and known to be productive (Fitzhugh 2001).

**Functional Implications of Time, Energy and Risk Reduction Models**

Each of the models exploring technological organisation in hunter-gatherer subsistence emphasises the conditions under which curated or expedient technologies (e.g. Binford 1973, 1977, 1979; Torrence 1983; Bamforth 1986) and (following Bleed's (1986) publication) reliable or maintainable design systems are to be expected (with the exception of Hiscock 2006 which is discussed in the following section). The physical manifestations of these systems are argued to be reflected, archaeologically, by relative frequencies and types of specialised or generalised forms present at a site (Bleed 1986; Parry and Kelly 1987; Kelly 1988; Kelly and Todd 1988; Torrence 1983, 1989b; Myers 1989; Jeske 1992; Bamforth and Bleed 1997). These outcomes assume that clear differences exist between specialised and generalised forms so that each is identifiable in the archaeological record. As such, a number of additional, but implicit, assumptions necessarily exist about the relationship between artefact morphology and function.

One such assumption is that, in order for a dichotomy between specialised and generalised forms to exist it is necessary for different morphologies to be better suited to the performance of specific tasks. That is, ideal combinations of features that are specific to a particular task must exist, be known to the knapper and be selected, in order to develop specialised implements capable of achieving higher performance levels than any other combination of features in the completion of that task. This assumption dictates that specialised implements will differ morphologically relative to the function they are designed to perform. Another assumption is that, despite certain features performing particular tasks better than others, it is still possible for one form to perform a wide range of tasks sufficiently well as to not justify the additional investment in time argued to be required to manufacture a more specialised implement for each function. This, in turn, begs the question of how much more efficient a particular morphology must be to justify the further investment in time to manufacture it and to qualify it as a specialised form. This idea further assumes a correlation between investment of time and returns, implying that greater investment in time necessarily results in a more efficient tool. A third assumption is that both generalised and specialised tools are efficient within their relative circumstances and that shifts in design systems are not accompanied by shifts in the performance of the artefacts themselves. If an implement is designed to fulfil a specific function, it must be
good at it. However, most importantly, it is assumed that each of these differences is real and identifiable in the archaeological record. This idea is best illustrated using the arguments of Torrence (1983, 1989b) as an example. Torrence argues that toolkits have different formats, each of which has different implications for functional operation and are argued to be reflected in assemblage composition, diversity and complexity. In her discussion, composition is argued to relate to a range of functions performed, as evidenced by the range of morphologies present, while diversity refers to the degree of specialisation detectable in tool forms. Complexity refers to the number of components required to make the artefact function; the more components the more complex and the more efficient the tool will be. While not explicitly stated, Torrence uses complexity only in reference to composite tools and is not relevant to individual artefacts. Nevertheless, the general assumption is made that different functions can be differentiated from one another on the basis of artefact form which, in turn, implies that different morphologies are unlikely to have been used in the same tasks. In addition, it is implied that specialisation is, in some way, detectable by morphological difference from less specialised tools and that each of these performs only the one specific function, hence diversity in specialised tools indicates diversity in artefact function. It is therefore assumed that form and function are uniquely connected and that, at a general level, it is possible to look at artefact morphologies and separate them on the basis of function, without actually identifying the function.

In reality, archaeologists at present have no means of testing any of these assumptions. In the absence of adequate testing of what constitutes an effective tool, we are currently unable to verify the propositions upon which technological organisation models are based. As yet, we do not know which morphological features contribute to edge effectiveness or how much, if any, morphological variation is necessary before the artefact is better used in a different task. Jochim (1989:111) identified this problem almost 20 years ago stating: ‘Tool reliability may, indeed, by enhanced by an increase in tool size and component redundancy, for example, but by how much? What is the scale by which we measure reliability and how does reliability vary on this scale with linear measurements of tool size? Is a projectile, with four microlithic barbs, effectively more reliable in its performance than one with only two?’ Yet, despite the increased support for technological organisation models across the globe, these questions remain unanswered. Further, differences may exist in the use-longevity of different morphologies that are entirely unknown, with some combinations of features better suited to long term use and others only capable of performing well for limited periods of time.
Previous discussions of artefact use-lives have investigated potential for reduction relative to mass and manufacturing costs only, and not explored the possibility that particular combinations of features may require less frequent maintenance by holding their functional edges longer than others (e.g. Hayden 1989; Kuhn 1994; Shott 1989, 1996b; Shott and Sillitoe 2005). In fact, having specifically commented that ‘The edge efficiency and rate of edge dulling of lithic materials used in specific contact situations is one of the most obvious factors’ affecting artefact use-life, Hayden (1989:10) fails to comment on, or investigate the issue any further. The existence of differential rates of decline in edge performance may lead to some morphologies requiring more frequent and extensive maintenance than other more robust morphologies, such that in some cases retouched and unretouched forms may represent the same quantities of use. In the absence of this information it is difficult to determine on what basis specialisation would differ from generalised morphologies given that we are currently unaware of the morphological combinations necessary to fulfil basic performance requirements. It is also necessary to determine to what extent morphology contributes to effectiveness and which variables have the greatest impact. This is likely to differ according to function. However, if the functional edge alone is the only necessary component then it is foreseeable that generalised tools may take many different overall forms or be very similar but have a number of quite different edge morphologies on several sides. If this were the case it would be possible for artefacts to be both generalised and specialised, in which each of several functional edges was particularly effective for a different task. It may also be possible for one particular combination of features to perform a range of tasks to an adequate level, requiring only one functional edge to be relevant to the overall tool morphology. Conversely, many specialised tools may exist in different forms but be equally effective, provided the right combinations of features are present on the working edge. If this were the case, the amount of assemblage variation able to be explained by variation in function becomes questionable. Further, if edge morphology can be demonstrated to be an important determinant of function, it is possible that theoretical dichotomies between specialised and generalised forms are largely irrelevant. The dramatic differences generally identified to exist between these two strategies could be reduced to slight differences in the shape of an edge. If multiple functionally effective edges can be used on the one implement, a dichotomy between specialised and generalised tools may not exist at all.

At present, the only means available to archaeologists of monitoring some of the risks involved in technological activities is through event tree analysis of production sequences (Bleed 1996, 2002). These enable the identification of production failures and the
recognition of their material correlates, offering some understanding of the risks involved in the manufacture of specific artefacts. However, the ability of these artefacts to minimise risks induced by the limited availability of other subsistence resources through increased functional utility remains unknown.

It is therefore clear that, despite the ingenuity and widespread acceptance models relating technology to situations of time, energy or risk stress, at present they are difficult to verify due to the lack of testing of their functional assertions. Theories relating patterns of hunter-gatherer mobility and raw material procurement to the development of technological systems discussed below are subject to similar limitations.

Mobility Patterns

Hunter-gatherer mobility and the requirements that it places on the transportability of toolkits (expenditure of energy) has become an increasingly popular explanation of variability in technological systems since Binford (1979) first differentiated between logistical and residential mobility strategies in resource procurement. Mobility has been argued to be a means of coping with resource distributions, while technology is identified as facilitating efficient resource procurement (e.g. Hiscock 1984, 1996a; Kelly 1983, 1992; Shott 1986, 1990; Parry and Kelly 1987; Lurie 1989; Andrefsky 1991; Kuhn 1994; Morrow 1997; Cowan 1999; Wallace and Shea 2006 see recent arguments by Bamforth 2002 for opposing views). As such, technological requirements are seen to fluctuate with mobility strategies and differences in tool assemblages and production debris fluctuating accordingly. Residential mobility involves the movement of an entire group throughout the seasonal rounds (Binford 1980). The differential distribution of suitable raw materials relative to tool-use locations and the need to protect against unanticipated events arising from high mobility, such as time constraints on the continual manufacture of new artefacts at each locality, necessitate artefact transport (Binford 1979; Camilli 1982, 1988; Keeley 1982; Shott 1986, 1990; Parry and Kelly 1987; Nelson 1991; Kuhn 1994; Cowan 1999 see also Bamforth 1991b). A common assertion has been that, in order to meet transportation requirements, flaked tools should be small (including relatively few items) and light weight (Torrence 1983; Shott 1986), curated and designed to be both maintainable, multifunctional and flexible to meet variable circumstances likely to arise during frequent movement between localities (Binford 1979; Lee 1979; Shott 1986; Kelly 1988, 1992; Kelly and Todd 1988; Lurie 1989; Hiscock 1994a; Milliken 1998). Available materials are predicted to be heavily conserved, with knappers adopting strategies for reduction that conserve available
material and intensifying use of artefacts forms known to maximise amount of working edge relative to artefact weight. Bifaces and prepared cores, in particular, have been widely argued to meet the requirements of highly mobile groups (Andrefsky 1986, 1994; Odell and Cowan 1986; Parry and Kelly 1987; Kelly 1988; Kelly and Todd 1988; Nelson 1991; Hiscock 1994; Cowan 1999; Bamforth and Becker 2000). In contrast, logistical mobility refers to low level residential mobility with reliance upon logistical forays by small groups of individuals who procure food from elsewhere and return it to the permanently settled group (Binford 1980). This type of mobility pattern allows the exploitation of resources with a known distribution, without restricted carrying requirements. Familiarity with available resources means that the manufacture of specialised implements, designed to perform with maximum efficiency and reliability in order to target specific resources, is to be expected. Where mobility is low, curated strategies and reliable design systems are thus predicted (Binford 1979; Lee 1979; Shott 1986; Kelly 1988, 1992; Kelly and Todd 1988; Lurie 1989; Hiscock 1994a; Cowan 1999), as are reduction strategies such as bipolar reduction, which have been shown to conserve available materials and avoid forays for more raw material (Parry and Kelly 1987; Kelly 1988; Lurie 1989; Hiscock 1996a). Where raw materials are readily available, however, links have been identified between expedient core technologies and increased sedentism/low mobility (e.g. Parry 1987; Parry and Kelly 1987; Wallace and Shea 2006). Under these circumstances, both the manufacturing and procurement costs of technology are low due to the ready availability of raw materials and the relative ease of striking off a new and suitable flake in preference to reshaping an old one. Assemblage complexity and diversity have also been discussed in relation to mobility patterns (Shott 1990); where residential mobility is high, successive occupations of sites are argued to be 'characterised by similar remains and low task specificity' (Shott 1990:21). High logistical mobility, by comparison, is argued to be 'more spatially differentiated, with higher task specificity at any given location. Consequently, they generate archaeological records of greater complexity and variability' (Shott 1990:21).

More recently, opposition between the desired characteristics of portability and durability/functional versatility have been identified (Kuhn 1994), in an effort to balance competing goals between artefacts that are lightweight for portability but large enough to cope with these needs. Measuring artefact utility against size, Kuhn (1994) found that the utility of tools reaches a point beyond which large increments in size/weight yield only minimal gains in utility. He therefore argues that larger tools are not necessarily indicative of greater utility, with relative gains in retouched tools decreasing as size increases (Kuhn 1994:432). Kuhn concludes that a toolkit composed of several retouched tools or blanks
of optimal, or suboptimal size, will provide greater utility than a core of comparable mass. This is because cores will generate more wastage in the conversion of mass to suitable flakes, whereas retouched tools or blanks are immediately useable.

**Functional Implications of Mobility Models**

Some of these models of mobility have been tested, with patterns of reduction strategies, such as the utilisation of bipolar reductive techniques in association with low residential mobility, able to be detected archaeologically (e.g. Parry and Kelly 1987; Hiscock 1996a). However others, in particular those that lack direct material correlates, suffer from the same inability to be tested as models of energy, time and risk reduction. In the absence of knowledge of minimal functional requirements it is difficult in many cases to determine to what extent mobility requirements have been catered for or how to identify which aspects of assemblage variation are the product of meeting these, rather than functional requirements. This is particularly the case with models which draw on assemblage composition and diversity as indicators of different technological systems (as discussed above). Mobility models also make a number of assumptions about the relationship between artefact size and performance. For example, the argument that artefacts used by highly mobile groups should be lightweight and multifunctional assumes that size has no effect on function. In effect, the argument presupposes that artefacts are capable of being small, multifunctional and lightweight while still performing at a high level of efficiency. In reality, we have little idea what it requires for an edge to perform effectively in order to determine the effect of size and capabilities of multifunctionality.

A further assumption is that qualities such as flexibility and versatility are possible. While it is evident that artefact edges may be reduced and changed through rejuvenation and maintenance activities, it is not clear what effect these activities have on the functional capacity of the new edge created. As a reductive process, the action of reshaping and rejuvenating an edge necessarily removes material from the artefact and, subject to the type of retouch utilised, generally results in changes to the features of the edge. Unless edge morphology has no effect on performance, it therefore seems likely that the processes of reshaping necessarily alter, in some way, the functions for which the artefact may then be suitable. Yet, technological organisation models tend to assume that productivity remains the same throughout the artefacts use-life, and that changes to form do not affect function. Kuhn's (1994) and Hiscock's (2006) alternative arguments are subject to similar problems; both explore the relationship between artefact size and utility in the absence of information.
about function. The assumption is that, functionally, specialised tools can be manufactured and easily transported and that no compromise in function accompanies these changes. Whether mobility is argued to be best enhanced by the production of large, multifunctional tools (e.g. Shott 1986; Bleed 1986) or a number of small, specialised tools (Kuhn 1994 see also Hiscock 2006 above), artefact function must inevitably constrain the overall size and mass of artefacts. If artefacts become so small that they are no longer productive, there is unlikely to be any reason to continue to transport them (Kuhn 1994). Likewise, the relative advantage of producing standardised, but disposable, forms (Hiscock 2006) is dependent upon that artefact’s functional utility prior to discard. Consequently, the degree to which artefacts may be reduced to suit mobility requirements (and/or reduce risk Hiscock 2006) is likely to be dependent upon meeting initial functional requirements and the amount of change possible without compromising them. In addition to a dependence upon flawed assumptions of dichotomies between specialised and generalised forms and qualities such as flexibility and reliability, arguments relating mobility strategies to technological systems fail to take functional requirements into account.

A final variable considered to influence the development of technological systems is the location and quality of available raw materials.

**Raw Material Quality and Availability**

Raw material quality and availability are widely argued to be primary determinants of technological variation and therefore assemblage composition (Binford 1973, 1977, 1979; Hayden 1977, 1979; Gramly 1980; Torrence 1983, 1989a, 1989b; Hiscock 1984, 2006; Bamforth 1985, 1986, 1990; Kelly 1988; Kelly and Todd 1988; Jeske 1989; Jochim 1989; Lurie 1989; Kuhn 1991; Marks et al. 1991; Andrefsky 1994; Newman 1994; Shott 1994; Holdaway et al. 1996; Milliken 1998; Bond 2004). Raw material is seen to condition artefact manufacture in a number of ways. The nature of the raw material outcrop will directly affect the size and shape of artefacts able to be manufactured from the material (Hiscock 1984; Goodyear 1989; Stiner and Kuhn 1992; Andrefsky 1994; Kuhn 1995b; Brantingham et al. 2000). This, in turn, dictates the extent to which artefacts may be reduced and reused because an artefact can only ever be smaller than the piece from which it was manufactured. It may also dictate the reduction strategies utilised by the knapper (Stiner and Kuhn 1992). The homogeneity of any raw material and its fracture properties also dictate the quality of artefacts which can be produced as well as their suitability for performing various types of tasks. For example, homogenous and micro-crystalline raw
materials are often thought to be suitable for cutting and slicing activities, and are argued to be flexible in terms of creating and maintaining these types of functional edges. Raw materials with a good degree of plasticity can sometimes be transformed from shape to shape with ease (McNiven 1994). For flaked stone artefacts, the quality of raw material directly affects the likelihood that an artefact will be continually reused or reduced, simply because raw materials with poor flaking properties will be difficult to reduce in a controlled manner and are likely to produce considerable wastage (Hiscock 1984). However, these same qualities, regarded as beneficial in the manufacture and use of flaked artefacts, are known to be disadvantageous when involved in high-impact activities and have a tendency to shatter upon impact. Obsidian is one such example. The glass-like homogenous nature of obsidian allows it to be easily flaked and reshaped but also to shatter with ease under high impact. These differences in the activities for which raw materials are best suited suggest the existence of an interaction between raw material and function.

Raw material availability, the frequency and distribution of material outcrops, is also argued to be a crucial variable (Hiscock 1984, 1996a; Bamforth 1985, 1986; Jeske 1989; Jochim 1989; Lurie 1989; Kuhn 1991; Andrefsky 1994; Ingbar 1994; Holdaway et al. 1996; Milliken 1998; Ricklis and Cox 1993; Bradbury and Franklin 2000; Brantingham et al. 2000; Wenzel and Shelley 2001). Assuming decisions are dictated by cost-benefit ratios, it is argued that where materials are abundant, there is no need to conserve them and an expedient technology will be adopted (Binford 1979). The basic premise behind this assumption is that it is easier to strike off a fresh flake than to reshape an old one and that the edges on primary flakes are more effective than on retouched edges (Hayden 1977, 1989; Bamforth 1986). Where raw materials are abundant, primary flakes are expected to outnumber retouched flakes. However, such expedient use of materials will only represent a cost-effective solution where raw materials are readily available (Bamforth 1986; Jeske 1989; Andrefsky 1994). In situations where raw materials (or at least suitable raw materials) are scarce or involve considerable efforts to procure, mechanisms designed to preserve available raw materials will be implemented, thus reducing the need to expend time and energy in procuring more materials (Bamforth 1986; Andrefsky 1994; Milliken 1998). These may include: prolonging an implement's use-life by employing reduction techniques that remove as little as possible of the material whilst creating a new sharp edge (Hayden 1989; Milliken 1998; Brantingham et al. 2000); standardization in artefact form, allowing maximum productivity from available material (Jeske 1989; Hiscock 2002, 2006); abundance manufacture strategies (Hiscock 2006); increasing maintenance and recycling of available tools (Bamforth 1986; Wallace and Shea 2006); conserving precious materials
through the use of less valuable materials to perform actions that do not strictly require the use of precious materials (Ricklis and Cox 1993) or adopting techniques that allow artefacts to be reduced further than would otherwise be possible (e.g. bipolar reduction - Hiscock 1994b).

Functional Implications of Raw Material Quality/Availability Models

The importance of raw material requirements on the technological systems capable of being manufactured is difficult to deny with the various properties of the raw material impacting on a great number of attributes of artefact form. Yet the restrictions which raw material considerations are likely to impose upon notions of flexibility, maintainability, reliability and so on are rarely considered by proponents of these design systems. Likewise, if morphology and function are as closely related as is currently assumed, the ability of raw material to alter morphology so dramatically presupposes a corresponding alteration to the functions of the artefacts produced. In fact, a general failure to consider the interactive effects of other aspects of hunter-gatherer behaviour characterises current approaches to the organisation of technology, and leads to an important question relating to the notion of ‘toolness’ and its role within the interpretation of prehistoric behavioural systems.

THE ORGANISATION OF TECHNOLOGY AND ‘TOOLNESS’ – WHAT IS A STONE TOOL?

The most distinctive features of arguments modelling technological organisation are their application and interpretation in isolation from other equally important variables (notable exception is Milliken 1998). In each argument, the focus is restricted to whichever characteristic the archaeologist identifies as being defining and most important to their specific concept. This focus on individual properties of subsistence behaviour such as risk reduction, mobility requirements, material conservation and so on and the need to identify singular defining characteristics of technological development implies that technology is the product of individual variables. This suggests that tool use is not connected to different dynamics and contexts or the product of a number of interacting variables, each of which contributes to the ways in which stone artefacts function within larger behavioural systems. Essentially ‘reducing the list of variables we consider to only one...makes it impossible either to examine alternative answers to the question we are asking or to recognise the potential interactions between multiple causal processes’ (Bamforth 1991b:217). If stone tools are an important means by which hunter-gatherers
exploited the many resources available to them, they may be best viewed as dynamic and interactive entities in which all relevant variables are considered to have an impact (Milliken 1998). Implicit in each of these models is the idea that artefacts are designed to fulfil a specific function and that they will perform these functions efficiently. Yet each of these models regularly identifies circumstances under which artefact morphology will change, with no discussion of the effect these changes might have on artefact function or performance. Given the emphasis that each model places on notions of artefact specialisation and the ability to identify this aspect of technology through morphological difference in archaeological assemblages, it is a major flaw in the literature that discussions of morphological change are made in the absence of any qualification of the functional implications of these changes. The implication is that changes in form either improve artefact function (as in risk reduction or time-stress models) or remain the same without any evidence offered to support either of these conclusions. Further, it must be recognised that shifts in the effects of one variable will necessarily have an effect on other relevant variables. For example, the type of raw material available for use will affect the degree to which a technology may be capable of curation, maintainable, flexible, reliable or versatile by affecting manufacturing and maintenance capabilities. The outcome of choices made in the earlier points along this continuum strongly affects available choices further down the line. Successful use relies on successful production which relies in turn on successful raw material procurement (Bamforth and Bleed 1997). Compounding the effects of raw material type and blank morphology are functional requirements and the limitations these place on the ability to improve reliability, flexibility and so on.

The failure to interpret technological systems as dynamic entities that are both responsive to, and limited, by other aspects of technology means that many of these models represent idealistic interpretations of assemblage variability at archaeological sites by oversimplifying the forces acting upon the manufacture and use of stone artefacts and the varied roles they play in subsistence behaviour.

DISCUSSION AND CONCLUSION

The discussion presented in this chapter reveals a number of important and pervasive flaws with the current use of technological organisation to expand concepts of tool function to include variables relating to technological strategies. These problems can be summarised as follows:
1. A widespread dependence upon assumptions of the relationship between artefact form and function that are currently untested. These presuppose that desirable qualities such as specialisation, maintainability, versatility and so on are physically possible.

2. A lack of knowledge about what constitutes an effective edge in the performance of subsistence tasks. This has resulted in an inability to test propositions relating desirable qualities of technological systems to assemblage composition, through an inability to differentiate between morphological features that are functional requirements and those that represent qualitative improvements to other aspects of subsistence.

3. Failure to recognise tools as dynamic entities that are responsive to a number of interacting variables, such that changes in one aspect of tool use will invariably affect others.

4. Implicit assumptions of artefact performance and effectiveness, regardless of the nature and extent of morphological change induced by achieving qualities such as reliability or versatility.

5. Failure to appreciate that functional requirements necessarily limit the extent to which various mechanisms will be capable of inducing technological change, as well as the magnitude of change possible. Raw material type and blank morphology are likely to be equally limiting.

Each of these problems arises from a general failure to acknowledge that the primary role of artefacts is to perform maintenance and survival activities such as: cutting meat, scraping hide, chopping wood and so on. In seeking to attribute artefacts broader functions within behavioural systems, archaeologists have failed to first ensure that basic functions are still attainable. The primary role of any implement must surely be to complete a desired task to a minimum level of competence. That is, 'All tools must meet certain baseline requirements of effectiveness and accessibility' (Bamforth and Bleed 1997:112). In order to meet these requirements, a series of performance criteria or priorities must be met, irrespective of context (Schiffer and Skibo 1997). These are the characteristics that make the artefact worth manufacturing in the first place; the thresholds without which the artefact fulfils no role or purpose. The decision to accommodate functional requirements such as portability and versatility will inevitably be largely
peripheral to immediate function. It is our ignorance of these requirements that is currently impeding our ability to construct and test higher level theories of artefact function. Artefacts are assumed to be efficient simply by virtue of their being there, rather than by any evidence to suggest this is the case.

As a consequence it is clear that, at present, models of technological organisation fail to adequately explain or identify the role of artefact function within broader behavioural systems. Independent research into the relationship between artefact form and effectiveness is essential if we are ever to test current models and increase our understanding of artefact variability and technological change. Such data have been specifically called for by a number of archaeologists (e.g. Torrence 1983; Jochim 1989; Bamforth and Bleed 1997; Fitzhugh 2001), but has yet to be generated.

The following chapter explores the minimal research done into artefact effectiveness and identifies an appropriate system for exploring efficiency and effectiveness in artefact manufacture and use.
CHAPTER 5

UNDERSTANDING STONE ARTEFACT EFFICIENCY AND IDENTIFYING PERFORMANCE CHARACTERISTICS

INTRODUCTION

The previous three chapters identified a widespread dependence upon assumptions of efficiency in current interpretations of artefact function. The dependence of wear analyses on typological constructs has meant that current analytical and interpretive techniques have been based on assumed, rather than demonstrated, relationships between form and function. In the same way, investigations into the organisation of different technological design systems have been shown to be reliant upon untested relationships between function and unique morphological markers in the archaeological record. Given the widespread dependence upon notions of artefact efficiency throughout the literature, and the current inability to test the interpretive value of these concepts, the exploration of efficiency, as a concept, is necessary. Before statements can be made relating artefact morphology to technological efficiency, the concept of efficiency as it pertains to the manufacture and use of stone artefacts, must be defined and an appropriate theoretical framework within which to explore relevant relationships must be identified. Fulfilment of both these requirements is attempted in this chapter. However, due to the paucity of previous research into this aspect of lithics analysis, a framework specific to the exploration of efficiency and morphology in stone artefacts does not currently exist. It has therefore been necessary to draw on research from other fields which have given greater consideration to these concepts and constructed suitable interpretive frameworks - primarily ceramics analysis - and alter them to suit the specific needs of stone artefacts.

PREVIOUS INVESTIGATIONS OF ARTEFACT PERFORMANCE

Current knowledge of artefact effectiveness comprises a number of unqualified and unquantified observations by wear analysts over the course of experimentation and a handful of poorly controlled, or narrowly directed, experimental programs. While these explanations and investigations fall short of generating accurate and exhaustive data relating artefact morphology to performance, they highlight a number of potentially relevant
variables and signal important areas for future investigations into artefact effectiveness. Each is discussed below.

**Casual Observations of Edge Performance**

The greatest source of available information on stone artefact performance comprises casual observations by wear analysts. As the product of investigations into the development of wear, these observations are subject to the same lack of experimental control illustrated in chapter 2 for other aspects of use-wear experimentation and may therefore be problematic and unreliable. Further, as observations that were not central to the goals of use-wear experimentation, the resultant data is neither qualitative nor quantitative. Nevertheless a number of variables likely to impact upon artefact performance have been identified which are worthy of further investigation, including raw material, edge morphology, contact material and motion of use. These are discussed below.

Raw material has been widely noted to affect the extent to which an implement can be resharpened, reused and recycled relative to its mechanical and edge holding properties (Fullagar 1986; van Gijn 1990; Hurcombe 1992; Kamminga 1982; Knutsson and Taffinder 1986; Moss 1983a; Olaussen 1983; Semenov 1968; Strauss 1980; Sussman 1985, 1988; Vaughan 1985). Raw materials, with strong edge holding capabilities, have been assumed to be more desirable in use activities because they reduce the frequency of rejuvenation activities. Very few studies, however, have sought to quantify the relationship between the qualities of raw materials and its functional limitations (although exceptions such as Keller 1966 exist).

Edge shape, both in plan and profile, as well as edge-angle, have been found to affect resilience and resistance to damage (van Gijn 1990; Kamminga 1982; Keeley 1980; Keller 1966; Moss 1983a; Tringham, et al. 1974; Vaughan 1985). Working edges that are straight in plan (as opposed to concave or convex) are observed to sustain less edge-damage during use than those with curved edge plans (van Gijn 1990; Moss 1983a, 1983b, 1986a, 1997) and high edge-angles to scar less frequently than low edge-angles (Tringham et al. 1974; Odell 1981; Kamminga 1982). These observations suggest that edge morphology may be a determining factor in scar frequency which, in turn, is thought to affect edge performance and the extension of an artefact’s use-life. Relationships between the shapes of the edge in section and use action have been noted. Van Gijn (1990) observed that edges with straight
ventral and dorsal surfaces tend to be employed in longitudinal cutting activities, while edges with combinations of convex, concave or straight aspects tend to be favoured for transverse scraping motions.

Edge-damage is widely considered to adversely affect edge performance (Moss 1983a; Olaussen 1983; van Gijn 1990). In a well controlled series of experiments into the effects of heat treatment on the nature and speed of edge-wear development, Olaussen (1983) found that heat treatment significantly altered the susceptibility of flint to edge-damage. Heat treated flint is found to wear more quickly than untreated flint, with greater severity and incur a significant increase in frequency of edge-damage. Heat treated flint artefacts are therefore argued to be effective for shorter periods of time than untreated artefacts. These inferences suggest that investigations into the effects of edge-damage on edge performance and longevity might be profitable.

The contact material worked and the motion of use involved are also noted to affect rates of edge-wear (Patterson 1981). For instance bone-working is found to rapidly diminish the productivity of an artefact while sickle blades remain productive (though with diminishing efficacy) for extended periods of use (Hurcombe 1992; Keeley 1980). Sawing activities have also been suggested to diminish edge productivity at a much higher rate than scraping activities (Keller 1966).

In addition to identifying variables likely to affect artefact productivity, causal observations on performance in the wear literature have indirectly suggested information relevant to investigations of artefact performance. The first of these is a lack of correspondence between artefact form and function, with variations in artefact function detected on artefacts within the same morphological tool class, while artefacts that are morphologically different have been found to be functionally similar (Ahler 1971; Hester and Heizer 1973; Moss 1983a). Multiple functions have been detected on different edges of the same implements while the noted use, reuse and modification of artefacts and broken items suggest that, in some cases, virtually any edge will suffice. These findings highlight likely complexities of relationships between artefact form and function but, more importantly, they suggest that the relevant morphological features contributing to artefact function may relate to individual edges, rather than to entire artefacts. This means that observations between form and function may be more profitably sought by shifting the scale of observation from overall artefact morphology to the specific characteristics of individual edges.
Supplementing the material provided by wear analyses, is a handful of studies that have specifically explored artefact performance. However, only three studies relate to flaked stone artefacts. Each of these is narrow in focus and exercises limited control of variables, with action, raw material and contact material the only variables discussed in any detail. As a consequence, the precise effects of individual or interacting variables upon artefact effectiveness are unknown. However, in combination with a number of studies on stone axe performance and a more recent investigation into the relationship between morphology and performance on metal saws (Bleed and Bleed 1997), these studies provide a basis for identifying variables worthy of more systematic investigation, and to establish more profitable lines of research for future studies of stone artefact effectiveness.

**Identifying Variables from Previous Performance Studies**

One of the first controlled investigations into artefact performance was Keller's (1966) exploration of the development of edge-damage with use action and its effects on utility. The study held raw material and contact material constant, but varied mode of use to allow estimates of the relative efficiency of different edges in different uses to be made from measurements of edge dullness. 'The mode of use which requires the greater length of time to produce dullness is thought to be more efficient' (Keller 1966:510), in which extent of use was calculated by the number of strokes performed. Certain modes of use were wear the working edges more rapidly than others, with cutting resulting in edges becoming rapidly unusable in contrast to scraping, in which edges could be used for longer. However, the experimental program failed to take into consideration a large number of potentially important variables such as edge-angle, size and shape or to control for variables such as speed or pressure during use, so it is possible that some of the differences noted between edge responses in different use actions are the product of additional variables. The subjective nature of the identification of edge 'dullness' also means quantification of differences between activities will be difficult. Nevertheless, the likelihood that different actions affect productivity and longevity differently suggests that controlled research into the effects of action on efficiency would be valuable. The changing effect of different actions on edge attrition also implies that particular morphological edge features may be better suited to particular tasks than others. If, for example, edges that are straight in profile and plan are less susceptible to edge-damage than concave or convex shaped edges, and edge-damage reduces the effectiveness of the working edge, it is likely that straight edges would be more favoured in longitudinal tasks than in transverse tasks.
Raw material has also been identified as affecting the susceptibility of an edge to damage. A mechanised experimental study investigating raw material as a functional variable (Greiser and Sheets 1979) indicated marked variation in resistance to edge attrition with different raw material properties. Attrition of isotropic and microcrystalline materials was noted to occur through regular edge scarring while granular materials exhibited a gradual wearing down of individual grains (Greiser and Sheets 1979). By controlling a large number of variables such as edge-angle, duration of use, contact material, as well as use-pressure, relief-angle, use-action and length of stroke (made possible by mechanising the use process), the results of this study provide some of the closest possible approximations of the effect of raw material on edge scarring. However, in the absence of quantified measures of efficiency and data relating rates of attrition to edge performance, the precise effects of different raw materials on changing edge effectiveness were not characterised. While it is possible that the results of this study incorporated the effects of the uncontrolled variables of plan and profile, they nevertheless identify raw material as an important variable affecting artefact performance that requires greater attention. Exercising control over relevant variables enabled Greiser and Sheets (1979) to control raw material as an individual variable and to explore its specific effects with minimal interference by other variables. Their program illustrates the value of exercising similar controls in subsequent investigations of other relevant variables.

Artefact size and edge retouch have also been noted to contribute to the effectiveness of flaked stone artefacts (Jones 1980). During a series of butchering experiments on goat carcasses Jones (1980) explored variations in the performance of retouched and unretouched flaked tools. Unretouched edges were noted to be sharper than retouched edges. However, retouched edges were argued to be more resilient to edge-damage and to last longer than unretouched edges. The use of larger tools was also argued to make the task less difficult (see also Mathieu and Meyer 1997) by being easier to manipulate, when hand-held, than smaller items. Jones' experiments were almost entirely uncontrolled with the actions, raw materials and artefact morphologies being constantly varied. These results are, therefore, more representative of unquantified and unqualified observations than of experimental testing. It may be, for example, that the observed resilience of retouched edges was the product of changes to both the shape and angle of the working edge through retouch, rather than of the retouch itself. Nevertheless, these results suggest that artefact size and edge retouch may represent variables affecting artefact performance worthy of clarification through refined experimentation.
Other potentially important variables impacting upon artefact efficiency have been provided indirectly by a number of studies exploring the performance of axes. Commonly, these studies compare the effectiveness of stone versus steel axes in tree-felling (e.g. Townsend 1969; Saraydar and Shimada 1971; Godelier and Garanger 1973; Coles 1979; Steensberg 1980). The time required to fell individual trees, or an area of forest, has been used to measure the relative efficiency of each axe type. Others have used stone axes to test different felling techniques, again identifying the most effective technique by the time taken to fell a tree (e.g. Iversen 1956; Saraydar and Shimada 1971; Coutts 1977; Carneiro 1979; Coles 1979). In general, experimental control was very poor in these studies, with only two attempting to control tree diameter (Carneiro 1979) or hardness (Coutts 1977; Carneiro 1979), while others introduced experimental bias with the involvement of several axe handlers (e.g. Iversen 1956; Coles 1979; Mathieu and Meyer 1997). Variables such as the shape and size of the axes used or the number of strokes involved, also were not controlled. The lack of control characterising many of these stone axe studies are such that very little quantitative evidence can be gleaned from their results, again emphasising the interpretive value of controlled experimentation and the identification of all relevant variables. The simplicity of the research questions asked in these studies, such as 'how long does it take to fell a tree with a stone axe' and 'are steel axes quicker,' has meant that detailed investigations into the specific features of an axe contributing to successful performance have not been asked. However, despite these problems, variables relevant to investigations of flaked stone artefact effectiveness and morphology can be suggested from their results.

Contact material hardness, the length of the cutting edge, the angle and the weight of the axe head have each been identified as important determinants of axe efficiency in the study of Mathieu and Meyer - one of the most well controlled investigations of the effectiveness of stone compared to metal axes. Seeking to answer specific questions relating artefact form with function, their program compared the performance of bronze, steel and stone axes. Variables such the length of the haft, blade width, shape and weight, tree type (hardness - four soft wood species and four hard), and size (diameter) were all controlled. Unfortunately, variation was introduced in the types of stone axes tested by comparing ground non-flint stone axes with flaked flint axes. In this case, it was not raw material alone that was varied, but also the techniques used to dress the working edges. Bronze and steel axes were found to be equally efficient at felling trees and significantly better than stone axes. However, the degree of difference in the time required to fell a tree, fluctuated with wood hardness, being most notable when felling hard versus soft woods. Differences
in efficiency were also noted between the manufacturing processes and/or raw materials of the stone axes tested. Ground stone axes were found to be duller and thicker than the unground-flint axes, making it harder to penetrate the wood than the sharper, thinner edges provided by a flint axe head. Ground stone axes were also found to be less likely to break than flint alternatives, particularly on harder woods. However, by allowing both raw material and manufacturing process to vary between axes, it is not possible to determine how much of these differences were due to raw material and how much was the product of manufacturing process. Nevertheless, these results suggest that the choice of axe may have been related, not only to the availability of raw material, but also to the type of flora being worked. A further implication of this study is the possibility that variables have interacting effects on one another, such that the decision to enhance one variable over another likely to have a number of flow-on effects to other aspects of tool use. The decision, for example, to use a flint axe may be accompanied by a greater rate of attrition and therefore a shorter use-life than would occur using a more resilient ground stone alternative.

The length and angle of the cutting edge and the weight of the axe head were also found to affect efficiency. The leverage provided by the length of handles, affected both the speed of swing and, therefore, the speed of felling. Axe heads with smaller angles on the cutting edge were found to be more efficient than thick, high-angled edges. Likewise, heavier axe heads were found to be more efficient than lighter heads (see also Jones 1980), while longer cutting edges were demonstrated to be more efficient than shorter edges (Mathieu and Meyer 1997). Each of these observations emphasised the likely importance of features of edge morphology, such as size and shape, as factors affecting edge performance. It may also be the case that both the features of the working edge and the overall size of the artefact being used make equal contributions to artefact performance (see also Dumont 1987).

Differences in axe efficiency were also noted to fluctuate with the size of the tree being felled (Mathieu and Meyer 1997). Plots of axe efficiency relative to tree size revealed that small trees (up to 10cm diameter) could be felled equally efficiently by any axe type but that as the diameter of the tree increased, the effect of species and hardness of wood became much greater. Once tree diameters reached 20cm or more, the advantages of steel axes over stone were substantially increased. These results suggest that basic levels of performance/productivity may be attained by a wide range of different variables; that is stone or steel, thin edges or thick, but that to increase efficiency beyond this point, features such as raw material, thin edges and low angles become increasingly important. This
means that certain combinations of features may be better suited to the performance of specific tasks than are others. In order to determine which combinations of features are better where, and under what circumstances, it would be advantageous to test the widest possible range of relevant variables.

A recent study by Bleed and Bleed (1987:189) comparing the performance of push and pull stroke saws, in an effort ‘to determine the extent to which alternative tool designs...make equally efficient use of human energy,’ gives further support to the likelihood that only very subtle morphological differences along the functional edge of a tool may be necessary to create quite substantial differences in performance efficiency. While not specifically related to stone artefact use, the purpose of the study was ‘to determine whether certain tool designs are intrinsically more efficient than others’ (Bleed and Bleed 1987:190), making it directly relevant to any discussion on the relationship between artefact form and performance. Using oxygen intake as a measure of efficiency, the study showed that the amount of oxygen consumed differed significantly with saw type, indicating ‘that not all hand saws make equally efficient use of human energy’ (Bleed and Bleed 1987:194).

Controls included three different types of saws, use action – using bow saws in both push and pull stroke motions, contact material and participants. Duration of use and measurements of oxygen intake were used to indicate performance. A number of important implications arose from the results. Firstly, comparisons between push and pull motions on bow saws revealed that ‘when all else is equal, a push power stroke is more energetically efficient than a pull stroke’ (Bleed and Bleed 1987:195). This result suggests that it may be possible for the same morphological edge to perform very differently depending upon the motion used. Secondly, of the four different designs tested, by far the most efficient was the pulled Japanese saw. This saw type possessed additional/alternative design elements such as the ability to use it with both hands, the avoidance of compressive stresses associated with push strokes, the ability to use a thinner blade and slight differences in the design of individual teeth - all of which may have contributed to the enhanced performance of Japanese pull saws (Bleed and Bleed 1987). The comparative success of this saw over similar alternatives suggests that only very subtle differences between relevant functional components of artefacts may be necessary to create large differences in overall productivity and ease of use. The principles established by Bleed and Bleed (1987) highlight a number of likely complexities associated with exploring artefact efficiency and edge effectiveness including morphology, use action and the possibility of interactions existing between the attributes of each.
A final lesson provided by investigations into tree-felling relates to the accurate measurement of efficiency. In each of these investigations, efficiency was measured either by the amount of oxygen used to perform particular actions (e.g. Saraydar and Shimada 1971; Bleed and Bleed 1987), or by recording the time taken to fell a tree or clear an area (e.g. Iversen 1956; Coutts 1977; Carneiro 1979; Coles 1979; Mathieu and Meyer 1997). The measurement of oxygen consumption is directly related to calories burned during activity and, as such, provides a good measure of the energy input required to produce a known output (Bleed and Bleed 1987). Differences in the speed of stroke used, different pressures etc, are all accounted for by an overall measurement of energy use. However, when using time as the measure of efficiency, variables such as the number of strokes involved, the intensity of the strokes (such as the number of blows per minute in tree felling) and the amount of pressure applied etc are important factors that are not measured. Time can only be an accurate measure of efficiency in circumstances in which each of these additional variables is held constant. In several of the studies discussed above, variables have not been held constant, with different individuals using different techniques to fell different sized trees, and yet time has been the primary determinant of productivity. As such, a considerable range in the number of cuts involved in felling each tree could be possible, making the time differences in performance of different axe types difficult to interpret in terms of efficiency. These results highlight the importance of identifying appropriate means of measuring performance and of recognising the relevant controls necessary in order to give interpretive value to the results generated.

The combined effects of casual observations of artefact performance and more specific studies of artefact efficiency, offer a number of important lessons from which to base future investigations of artefact performance and to thereby improve on current experimental procedure. These can be divided into two main areas: in experimental protocol and the identification of variables. Lessons of previous research findings which are directly relevant to the improvement of experimental protocol include:

1. Current knowledge of artefact effectiveness is distinctly lacking and many more investigations are needed to establish an appropriate interpretive framework by which to test theories of the relationship between artefact form and function.

2. Accurate measurement of the effects of specific variables requires the recognition and control of as many variables as possible.
3. Comparability between results requires the use of measurements of efficiency that are appropriate and accurate.

The ability to control all the relevant variables in an experimental program first requires their identification. The lessons provided by previous research which are relevant to the identification and interpretation of relevant variables include:

4. Artefact performance can be more readily assessed for individual functional edges rather than for overall artefact morphology. As such, a focus upon the specific features of the functional edge will be profitable.

5. A wide range of variables are likely to impact upon artefact performance and these include morphological features of the edge including edge-angle, shape in profile, plan and section, size and length, raw material and weight, use action and contact material type and hardness. Interactions may exist between any, or all, of these variables and edge performance.

6. There may additionally be non-linear interactions between those variables and performance. Studies of efficiency should be capable of taking into account the changing interactions of different variables.

Each of these lessons offers valuable information that might enhance the design of future investigations of artefact efficiency. However, before more detailed investigations of artefact efficiency can proceed and appropriate measures of efficiency and artefact performance can be determined, it is first necessary to define the concept of efficiency as it relates specifically to stone artefact manufacture and use.

MODELLING STONE ARTEFACT EFFICIENCY

While many archaeologists implicitly assume efficiency was integral to the technological design of stone artefacts, few define what is meant by the term ‘efficiency’ or how they intend to test it in an archaeological context (e.g. Hayden 1977, 1989; Torrence 1983, 1984, 1989; Parry and Kelly 1987; Kelly 1988; Bamforth 1986; Jeske 1989; Jochim 1989; Lurie 1989; Bousman 1993; Hiscock 1994; Fitzhugh 2001; Bamforth and Bleed 1997; Milliken 1998; Wallace and Shea 2006). Artefacts are often seen to increase efficiency of food procurement and resource exploitation by reducing the costs in terms of the time and energy involved in these activities while also increasing returns. As such, it is argued that
the most efficient forms, in any given task, will be those that provide the best ratio of cost to benefit in each activity.

In the absence of concise definitions of efficiency in the archaeological literature, the most relevant definition derives from economic theory. At its most basic level, efficiency is defined as ratio of output to input and is expressed as follows (Christensen 1982):

\[
\frac{\text{Output}}{\text{Input}} = \text{Efficiency}
\]

Efficiency is therefore a measure of the ‘amount of output produced per unit of input’ (Christenson 1982:420). Outputs comprise the total benefits gained from expended inputs, which include the total costs involved in any production system. As such, efficiency in any circumstance can be enhanced, or increased, by reducing the overall costs involved or by increasing overall net output. Economic models of efficiency differ from engineering models which focus on a single activity alone and determine the output produced per unit of input (e.g. mechanical efficiency, thermodynamic efficiency, energy efficiency, thermal efficiency etc).

Subsistence models outputs include food, raw materials and information while input comprises the information and labour involved in locating, collecting and processing food and raw materials. As efficiency will only be achieved when an appropriate ratio of cost to benefit is established, that is suitable to any given circumstance, efficiency can only be measured relative to the particular output seeking to be minimised/maximised or to the cost intended to be reduced. The extent to which a behaviour, action or artefact can be regarded as efficient is therefore dependent upon the specific goals of each individual situation or circumstance. The relative nature of efficiency as being situationally constrained makes it difficult to measure, with the potential for solutions to be regarded as efficient in one circumstance and highly inefficient in others.

As a consequence, the identification of efficient behaviour in any given circumstance will be dependent upon which costs the hunter-gatherer is seeking to reduce in a particular circumstance. Where time is limited, hunter-gatherers might be expected to utilise tools that increase the speed with which the task can be completed. Likewise, where energy or raw materials must be conserved, we would expect, to have low energy or raw material conserving options adopted. It is therefore necessary to determine what makes a given tool effective for reducing the costs of one type of input (e.g. time) over another (e.g. energy) or
whether it is possible for one artefact to effectively reduce the costs of all associated inputs – that is, what specific effects different morphological features and combinations of features have on activity outputs and how they relate to, or reduce, necessary inputs.

In the absence of an appropriate interpretive framework which relates behavioural efficiency to artefact morphology in the lithics literature, the following discussion refers views of artefact efficiency in ceramics analyses into one that is relevant to stone artefact analysis. This theory provides a framework for conceptualising how the physical, visible characteristics of stone artefacts may relate to less tangible behavioural efficiencies in prehistoric hunter-gatherer subsistence.

ESTABLISHING A FRAMEWORK FOR EXPLORING STONE ARTEFACT PERFORMANCE

Performance characteristics have been studied as determinants of variability in ceramic artefacts, with studies including investigations into vessel shape effectiveness (e.g. Braun 1980; Smith 1981; Ericson et al. 1972), manufacturing costs (e.g. Rye 1976, 1981) and the resistance of various ceramics to mechanical failure (e.g. Steponaitis 1984; Braun 1982; Feathers 1989; Skibo et al. 1989; Schiffer et al. 1994; Tite et al. 2001). The theory used to clarify issues of performance in ceramic vessels demonstrates great utility in the identification of performance characteristics in other classes of artefact, and in stone artefacts in particular.

One of the first serious attempts to explain difference in technological choice in production in terms of variation in the performance characteristics required in use, was conducted by Braun (1983; see also Tite et al. 2001), who argued that pots were primarily utilitarian in function and that decoration and additional visual markers play a secondary role in ceramic manufacture. As such, he considered all pots to represent a compromise in the artisan’s choices, balancing labour and material costs and the desired life expectancy of the pot. Emphasis was placed on the need not only describe features, but to understand and, more importantly, explain observed variation. Differences in the mechanical demands placed on vessels during manufacture and use were argued to contribute greatly to an artefact’s overall morphology, so that understanding the effects of different mechanical properties on performance would explain some of the observed variation between ceramic vessels. As such, ‘Variation in mechanically sensitive attributes of morphology and composition indicates variation in the relative importance of the factors conditioning the
compromise. In theory, these mechanically sensitive attributes, when their mechanical meaning is recognised, provide the archaeologist with the means for explaining ceramic technical variation, rather than just describing it' (Braun 1983:109).

Braun's ideas have been echoed and expanded by subsequent researchers in the field with ceramic vessels now generally argued to represent a balance between 'what the actor wanted to achieve, the techniques s/he chose to use, and the consequences of those choices' (Sillar and Tite 2000:3, Van der Leeuw 1991, 1993; Schiffer and Skibo 1987, 1997; Skibo 1994; Sillar 2003). Five main areas of 'choice' have been identified to affect any technology: raw materials, tools, energy, techniques and the sequence through which they are connected (Sillar and Tite 2000). Co-dependence between technical choices has also been emphasised with each found to be dependent upon another (Van der Leeuw 1991, 1993; Schiffer and Skibo 1987, 1997; Skibo 1994; Sillar and Tite 2000; Sillar 2003).

The best articulation of the relationship between technical choices and observed variation in artefacts has been provided by Schiffer and Skibo (1987, 1997) with the development of an interpretive framework that explains morphological variation through the identification and explanation of performance characteristics (e.g. Pool 2001; Sillar and Tite 2000; Tite et al. 2001). The framework has gained widespread acceptance within ceramics analyses, including support from several analysts who, despite viewing variation as the product of selective forces rather than choice (e.g. O'Brien et al. 1994; Neff 2001 in Cumberpatch et al. 2001; Neff 2002; Feathers 2003), nevertheless utilise the principles of Schiffer and Skibo's (1987, 1997) conceptual framework (e.g. Neff 1992; O'Brien et al. 1994). Relevant points were illustrated using examples from ceramics analysis but the framework presented is argued to be inspired by, and therefore relevant to, the explanation of variability in a wide range of artefact types which includes stone (Schiffer and Skibo 1987, 1997). As such, it is considered an ideal framework within which to investigate these same principles relating performance to morphology and to understand variability in stone artefact manufacture and use.

Developed in 1987 and revised in 1997, Schiffer and Skibo's (1997:28) theoretical framework is argued to 'incorporate[s] all causes of variability and establish[es] standards for specific explanations' of formal variability comprising 'an artefact's observable, often measurable, physical characteristics' (1997:28). Formal variability is explained as the product of different sequences of raw material procurement and artefact manufacture, maintenance and use (Schiffer and Skibo 1997, Schiffer 2003). In the case of stone
Understanding Efficiency and Identifying Performance Characteristics

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Artefacts, formal variability will include the raw material used, the size and shape of the artefact, the size and shape of working edges, edge thickness, the potential for retouch and the type and location of any retouch made. Artefacts produced by different activity sequences are therefore argued to differ in ‘design’ and, as such, the goal of the theoretical framework is to ‘guide the search for specific explanations of design variability’ (Schiffer and Skibo 1997:29) in order to establish why one particular sequence of activities was adopted in favour of others. Most importantly, the basic premise for this framework is that ‘design is driven by performance; that is, the artisan’s behaviour is influenced by an artefact’s performances in activities throughout its life history’ (Schiffer and Skibo 1997:29). The chances of an artefact continuing to be used, maintained or rejuvenated are therefore argued to depend upon its initial performance.

Schiffer and Skibo refer to all activities involved in raw material procurement and artefact manufacture as ‘technical choices’ (Schiffer and Skibo 1987:599, 1997:29) and are defined as the dependent behavioural variables within their framework. Each technical choice is argued to directly impact upon the artefact’s performance characteristics, which are defined as the specific capabilities of the individual elements comprising the artefact (Schiffer and Skibo 1997). Performance characteristics are argued to be strongly influenced by the artefact’s formal properties, which are, in turn determined by the technical choices of the artisan. The ability for technical choices to physically alter the formal properties of artefacts means that morphological variability between artefacts may be explained, in some cases, by knappers making different technical choices in raw material procurement and manufacturing processes. In addition, different artisans are likely to draw from different repertoires of potential choices, subject to their knowledge and experience.

The interrelationship between technical choices, formal properties and performance characteristics means that a single technical choice has the potential to affect an artefact’s performance characteristics in many activities along its ‘behavioural chain’ (Schiffer and Skibo 1997:31), and therefore its potential for further use. This is particularly the case with stone artefacts. Their reductive nature means that the capabilities of an artefact for further shaping or reduction is directly dependent upon previous technical choices relating to reduction and use episodes. The decision, for example, to create, or use, an acute edge rather than an obtuse angle may result in a finer edge that is more susceptible to breakage and abrasion which, in turn, may either reduce, or enhance, the edge’s ability to perform, or may increase the frequency with which resharpening is required. Furthermore, the reductive nature of edge retouching means that, once created, an acute angle can not be
reshaped to produce an obtuse angle of similar size, without extensive reshaping of the edge, and waste of available raw material. The choice to manufacture an acute edge-angle therefore limits the range of angles able to be manufactured and used in later stages along the sequence. Similarly, the suitability of an edge for resharpening will depend upon the quality of the raw material from which it was manufactured, the size of the exterior platform and so on (Schiffer and Skibo 1997). In addition, each technical choice will inevitably be accompanied by a number of different performance characteristics such as cutting edge effectiveness and edge holding properties that may differ with the duration and types of activities performed. Performance, or lack thereof, will therefore directly affect the artefact's involvement and the nature of that involvement, in later interactions.

Importantly, a single performance characteristic may be simultaneously affected by, or dependent upon, several technical choices and, in some cases, a number of technical choices may be required to maximise a desired performance characteristic. The complex effects of technical choices on performance characteristics are therefore argued to impose technological constraints on the artisan, precluding the possibility of producing a set of technical choices that arrive at maximum values for all relevant performance characteristics (Schiffer and Skibo 1997). Instead, any artefact design or morphology is argued to comprise a set of technical choices that are based on trade-offs or compromises in performance due, in accordance with technological constraints. It is therefore the interaction between technical choices and performance characteristics, rather than the analysis of single performance characteristics, that is considered crucial to the explanation of technological change (Schiffer and Skibo 1987, 1997).

The effects of various technical choices on performance characteristics are argued to be discovered through experimentation and trial and error (Schiffer and Skibo 1987, 1997 see also Ugan et al. 2003). Feedback allows the artisan to view the consequences of individual technical choices for performance and potential reuse. Those choices which fail to perform may lead the artisan to explore available alternatives and to abandon choices that are known to be fruitless. Poor technical choices are argued to be most readily identified in ongoing activities. For example, the use of obsidian for the manufacture of artefacts involved in impact activities such as chopping may result in the axe shattering after the first couple of blows. This rapid feedback allows the artisan to experiment with alternatives such as employing a different raw material. Ideally, feedback should allow the artisan to arrive at a set of technical choices that produce high, but not maximum, values for as many performance characteristics as possible.
Situational factors such as raw material availability, energy conservation, time pressure, risk reduction, mobility etc. are argued to dictate the performance characteristics most desired in any given circumstance (Schiffer and Skibo 1997:34). For example, performance characteristics that increase the speed with which a task may be performed are likely to be a priority in circumstances of time stress, while characteristics that provide an edge with good holding properties may be given highest priority where raw material availability is limited. It is therefore argued that artisans will ensure that manufactured tools cater to those performance characteristics given highest priority relative to situational needs, before accommodating characteristics that considered a lower priority. In order to determine how to prioritise different performance characteristics, Schiffer and Skibo (1987, 1997) make a simple differentiation between primary and secondary performance characteristics.

**Primary Performance Characteristics**

Prioritisation of performance characteristics is argued to be guided, at a basic level, by the need to attain the minimum performance values that make manufacture of the artefact worthwhile. The relative importance of each characteristic is predicted to dictate the order in which the artisan would combat these performance criteria. It is possible that several technical choices exist for solving a specific problem. However, this can create a flow-on effect whereby each solution creates new problems because of the effects of this particular technical choice on other performance characteristics etc. If a technical choice results in one or more adverse effect on other primary performance characteristics, the artisan is likely to continue experimenting with alternatives. As each problem is solved in turn, the artisan may have to adjust previous choices and so on, thereby resulting in enormous complexity (Schiffer and Skibo 1997).

The primary performance characteristics of each artefact is argued to differ according to the technological strategies employed, the tasks required of them, and the inputs seeking to be maximised/minimised. For example, in situations experiencing time stress, it is possible to suggest a number of primary characteristics likely to be valued, which are:

1. Raw material: the raw material used in artefact manufacture is able to be easily shaped and retouched in order to rapidly create particular morphological features.
2. Resistance to damage: artefacts are resistant to extensive damage, minimising the need to stop work and rejuvenate the working edge.
3. Functional effectiveness: artefacts can reach high performance thresholds of productivity in order to reduce the amount of time required to perform the task.

According to these primary performance criteria for the manufacture and use of stone artefacts in situations of time stress, artefacts should be made from appropriately flexible and resilient raw materials and possess those characteristics known to be highly effective at performing the task at hand. In order for artefacts to progress from one use interaction to another, the artisan must achieve threshold values in each of these primary performance characteristics (Schiffer and Skibo 1987, 1997). Artefacts involved in different activities or uses will necessarily prioritise primary performance characteristics differently. For example, it is unavoidable that artefacts that are intended for expedient use only are unlikely to be governed by the same rules as those outlined for curated artefacts.

However, central to the identification of primary performance characteristics in archaeological contexts is the ability to recognise their specific effects on the formal properties of the artefact — that is, their physical manifestations on stone artefact morphology. This necessitates some understanding of the morphological characteristics that contribute to functional effectiveness and how these may change with different activities. A further requirement is knowledge of how changes in morphological characteristics affect artefact performance in order to determine at which point minimal functional thresholds for a given activity can no longer be met.

Secondary Performance Characteristics

In contrast to primary performance characteristics, secondary performance characteristics address any additional characteristics that are not crucial to the artefact meeting threshold minimums. These may, or may not, be consciously selected for in the case of stone artefacts, due to the ability of stone to be reworked. However, secondary performance characteristics tend to be largely peripheral to the immediate function of the artefact and more directly related to situational requirements. Alterations to artefact form, such as reductions in size to accommodate mobility requirements, are regarded as meeting secondary performance requirements. The nature of secondary performance characteristics is such that they will only be achieved providing they make little difference to the attainment of the primary characteristics. Artisans are therefore expected to seek a technological solution that allows secondary performance characteristics to be catered for without compromising primary performance characteristics (Schiffer and Skibo 1987, 1997). Both primary and secondary performance characteristics will be constrained to the
extent that situation dictates the tasks required of an artefact and therefore the nature of
the primary performance characteristics. However, secondary characteristics should be
represented by morphological changes that are not directly related to the performance of
specific tasks and have therefore been suggested to be responsible for a much larger range
of variation in formal variability than primary performance characteristics.

**Trade-Offs and Design Compromise**

The degree to which both primary and secondary performance characteristics are able to
be attained will also depend on the existence of technical constraints on the system. Every
performance characteristic is likely to be affected by many technical choices and
interrelated variables. Accordingly, some technical choices will provide solutions to one
problem but, in doing so, create new problems for other performance characteristics. An
acute, weak edge being used in sawing activities, for example, may be strengthened by
enlarging the angle of the working edge, and improving its resistance to damage through
the division of the applied pressure over a wider contact area. However, in strengthening
the working edge, this increase in the contact area, millimetres from the working edge,
means a larger amount of material needs to penetrate the contact material, making
completion of the sawing task more difficult etc.

This lack of direct correlation between technical choice and performance characteristics
will necessarily impact upon the artisan’s ability to produce an artefact that optimizes the
values of all relevant performance characteristics (Schiffer and Skibo 1987, 1997). Compromises in artefact design are therefore likely with many performance characteristics
‘realising only suboptimal but acceptable levels’ (Schiffer and Skibo 1987:599). Alternatively, certain technological choices may have the capacity to compensate for
unacceptably low values created by others, improving the overall performance of the
artefact by offering unusually high values in a particular performance characteristic. Any
given design, therefore, represents a compromise between the primary performance
characteristics, secondary requirements and technical limitations under prevailing
situational conditions.

The relationship between technical choices, performance characteristics and formal
properties are such that Schiffer and Skibo (1987:608) believe ‘the priorities of each
technology are strongly reflected in the performance characteristics of resultant artefacts.’
This means that compromises will impact, in some way, on all artefact forms (Schiffer and
Understand~

Efficiency

and

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Skibo 1997; Ugan et al. 2003). However, the extent to which compromises and trade-offs can be detected in an artefact’s formal properties is dependent upon some knowledge of both primary and secondary performance characteristics and how they affect one another, in order to determine where and why compromises in features have occurred.

These same problems are likely to not only affect individual edge performances but also the extent to which time, energy or raw material preservation may be attained in efforts to maximise efficiency in one, or all, of these categories of input. It may be that considerable investments in time are involved in producing a tool that requires only minimal energy expenditure. Likewise, artefacts that rapidly perform a task may come at the cost of considerable physical effort to the knapper, or may only function for a short time, and result in more regular rejuvenation or replacement. Efforts to conserve raw materials may involve the use of low performing, but long lasting, morphologies or, alternatively, a particular edge may be extremely effective in performing a task but imprecise in execution compared to a lower performing morphology that produces a better quality result. Speed may come at the cost of quality, time may come at a cost to energy and durability may come at a cost to time and so on. Understanding these relationships between performance and their associated trade-offs represents a crucial area of prehistoric technology that has, hitherto, been neglected by lithic technologists and which must be rectified if archaeologists are to improve the accuracy of interpretations of prehistoric technological strategies in future.

SUMMARY AND CONCLUSIONS

Existing investigations into stone artefact performance have been shown here to be limited in their ability to elucidate the relationship between artefact form and function, being restricted both in number and in scope and with very poor control exercised over relevant variables. While a number of casual observations made by wear analysts have indicated potential variables likely to impact upon artefact performance, it is clear that, at present, archaeologists have failed to devote adequate time to the exploration of concepts of performance in stone artefacts. This is likely to be symptomatic of the widespread failure to recognise their necessity to the accurate interpretation of lithic assemblages. Regardless, lithics analysts are, at present, ill-equipped to explore these issues, lacking an appropriate theoretical framework within which to conceptualise artefact performance and an adequate understanding of the key variables involved. The use of a framework established by ceramics analysts for conceptualising relationships between morphological variability and
performance characteristics has therefore been advocated, predicated on a more extensive body of research into the performance characteristics of ceramics artefacts. This model advocates differentiating between primary and secondary performance characteristics as a means of prioritising the relevant qualities an artisan is expected to deal with first; thereby identifying the strongest determinants of formal properties relative to different circumstances. Conceptually this idea has great potential for explaining variation in artefact morphology but its practical application is contingent upon the ability to differentiate between those morphological features that represent primary performance characteristics and those that cater to secondary considerations in an archaeological context. By quantifying the varying effects of edge morphology on artefact effectiveness it is argued here that the identification of primary performance characteristics may be possible. The interaction between various technological constraints and trade-offs, as they relate to tool form and function, must also be identified in an effort to understand and quantify the interrelationships between relevant variables.

The ability of an artefact to make efficient use of time or energy will invariably be subject to its effectiveness in performing particular tasks. A tool, for example, that is ineffective at sawing is likely to be unable to reduce the time required to complete tasks that involve a lot of sawing. Any examination of artefact efficiency, regardless of context, must therefore begin with some understanding of how an artefact, or working edge, functions and what makes it suitable for particular tasks. In order to select for the specific features that enable the knapper to minimize time or energy expenditure, it is first necessary to identify which features those are and the physical manifestations associated with them.

A framework for modelling stone artefact efficiency relative to changes in edge morphology has been forwarded in this chapter, drawing from basic economic concepts of cost to benefit ratios. In the following chapter, the application of this method is discussed in a detailed outline of the experimental program undertaken for this research. The program is designed to allow the identification of primary performance criteria for stone artefacts in the performance of a range of tasks in order to establish values for maximum and minimum functional thresholds.
CHAPTER 6

EXPERIMENTAL INVESTIGATION OF ARTEFACT PERFORMANCE AND EFFICIENCY

INTRODUCTION

The previous chapter outlined a framework for exploring concepts of efficiency in stone artefacts and identified a number of variables noted, either casually or through experimentation, to affect artefact performance levels. However, in order to identify different forms of efficiency in an archaeological context it is necessary to understand and define the relationship between efficiency in various forms of stone artefact use and the formal variability in terms of morphology that they induce. The purpose of this chapter is to outline a means by which formal properties constituting stone artefact morphological variability can be explained and recognised in terms of maximising or minimising the relevant inputs and outputs on which efficiency is dependent. This chapter presents the experimental methodology used in this thesis to systematically test a wide range of morphological variables and quantify their effect on the performance of a desired task. Quantification of edge robusticity, as well as the ability to maintain performance of particular tasks for extended periods of time, has also been included as potential contributors to overall edge efficiency. From this basic understanding of edge morphology and performance, it is hoped that an understanding of morphological variability and implement efficiency in a broader behavioural context will be facilitated.

However, before discussing the program itself, it is necessary to briefly explore the value, role and general approaches to experimentation currently utilised in archaeological research and the types of results able to be generated from each.

FRAMEWORKS FOR EXPERIMENTATION

The discussion of experimental research outlined in chapter 2 highlighted the requirement for a number of necessary features of accurate and internally valid experimental programs: control of all known variables, systematic and balanced investigation of all treatments and statistical validity to enable identification and quantification of causal relationships. Experimentation in archaeological contexts usually falls into one of three research settings; a controlled laboratory in which artificial conditions prevail, the ‘real world’ in which an
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Effort is made to replicate real-life settings and make experimental programs as 'prehistoric' as possible (Kerlinger 1973; Tringham et al. 1974; Frison 1979; Odell 1980; Kamminga 1982; Mansur-Franchomme 1983; Moss 1983a; Fullagar 1986; Korobkova 1999; Skakun 1999), or a combination of the two in which certain variables such as contact material and action are controlled but the 'human' components such as pressure during use, intensity or 'handedness' are left uncontrolled. The vast majority of micro/use-wear and experimental studies of performance adopt the latter of these settings in an effort to replicate prehistoric patterns of wear or use, as closely as possible, whilst maintaining some understanding of the processes involved (e.g. Trinham et al. 1974; Kamminga 1982; Fullagar 1986; Hurcombe 1992). While there are a number of advantages to this approach in terms of generating 'realistic' wear patterns, a substantial number of drawbacks exist as well.

In real world settings, the goal of the experiment tends to be the completion of a task, in which pressure, speed of use, relief-angle and many other aspects of use are varied throughout the task, in order to saw through the bone, clean the entire carcass and so on. As such, multiple extraneous variables will contribute to experimental outcomes in a totally uncontrolled fashion. This precludes the ability to make valid comparisons between samples or to repeat or replicate the results for verification. More importantly, the precise effect/bias introduced by this uncontrolled variable upon results cannot be quantified and prohibits the identification of a causal relationship between the variables that are being properly controlled and tested. This means that despite the illusion of experimental control, the contemporary artefact use remains as complex and confused as the prehistoric situation it seeks to understand (Moss 1983a: 55).

Experimental programs which control some variables, but allow others to vary unchecked, suffer from the same misrepresentations of control as those which make no attempt to control variables at all. While it is true that controlling some variables means there may be fewer sources of variation contributing to the development of wear patterns, the inability to identify the specific effects of each are such that cause and effect relationships remain the same as that identified above for 'real world' experimental programs. Regardless, the conditions under which each experiment are conducted and the treatment of each variable is not constant and therefore non-comparable.

Conversely, the performance of experiments under laboratory controlled conditions avoids many of the complications associated with the incorporation of unquantifiable extraneous factors. Systematic exploration of individual variables, under constant and comparable
conditions, represents the only available means of identifying causal relationships between artefact use and the development of wear, and artefact form and functional efficiency. It must, however, be noted that due to the large range of factors likely to impact upon any given combination of attributes, experimentation is unable to exclude for all of them. It is only possible to control those variables known at the time to be relevant and, as such, accurate experimentation will always be dependent, to some extent, upon the state of the knowledge of the field itself (Plutchik 1968:168). It was therefore decided that a highly controlled study, in which each independent variable could be systematically isolated and varied, would be most capable of meeting the research goals outlined below and in Chapter 1 for this thesis.

Scientific Validity

The validity of highly controlled experimentation has been questioned by some archaeologists who argue that such conditions are not reflective of real-life situations and are therefore limited in their relevance to the interpretation of the real world (e.g. Tringham et al. 1974; Kamminga 1982). Attitudes such as these, however, ignore the fact that in most cases laboratory controlled experiments do not seek a direct explanation of field data but rather aim to develop sound interpretive principles from which a more precise understanding of the phenomena under investigation can be derived. ‘True scientific experiments do not try to replicate real life: instead, they isolate and control a small number of variables to assess how they interact in specified conditions’ (Sillar 2003:178). More importantly, the accurate identification of causal relationships is only possible by attaining internal validity within experimentation. Replications of real-life wear patterning or efficiency levels are of little value to archaeologists if the causes of each are unknown. As such, ‘the purpose of most experimentation is to test general propositions’ (Leary 1991:145) which may then be tested against data, as opposed to recreating generalised effects in the real world. The results of all experimental studies must therefore be subsequently tested against the data rather than directly transposed onto an archaeological setting.

EXPERIMENTAL PROGRAM

The following section details the experimental program carried out and discussed in this thesis. The methodology used, variables controlled and tested, preparations made and
equipment required to carry out experiments are each outlined below. The aims and predicted outcomes of this research are also discussed.

**Research Aims**

This program was designed to answer the questions:

*Does a consistent and identifiable correlation exist between edge scarring and use? And How and to what extent does edge morphology contribute to edge performance, attrition and use-life?*

In order to gain some understanding of the relationship between edge scarring and use, it was necessary to first address a series of related questions:

- Can patterns of edge scarring be shown to have a statistically significant relationship with aspects of use, such as action and contact material?
- Are there additional aspects of artefact use that contribute to the appearance or frequency of edge scarring?
- Is there a consistent relationship between important scar features such as initiation, size and termination and aspects of use (i.e. use action and contact material)?

Similarly, answering broad statements relating stone artefact edge morphology to performance levels in hunter-gatherer subsistence was dependent upon first gaining answers to a number of additional questions:

- What are the variables or combinations of morphological variables that contribute to stone artefact performance?
- What sorts of technical trade-offs exist?
- Is it possible to compensate for inadequacies in one variable by adjusting another?
- How does implement performance change during continued use?

In exploring the relationship between artefact morphology and performance it is important to know:

- How does artefact performance condition morphological variability in the archaeological record?

    Are particular morphological variants more effective in performing specific tasks than available alternatives?
Do combinations of variables exist for particular functions that result in levels of performance that greatly exceed all others? Does a single combination of variables exist that produces dramatically greater performance levels than others?

Do functional equivalences exist between morphologically dissimilar forms? Is it possible for different combinations of factors to perform the same tasks equally effectively?

Do functional thresholds exist in which a wide range of forms will be equally effective but beyond which particular qualities are required?

What is the effect of use-scarring on edge performance?

- What is the effect of morphological variability on artefact use-life?

Are the variables that are important to edge performance the same as those that affect the use-life of an artefact?

Do trade-offs exist between performance and longevity in which one must come at the cost of the other?

How does edge scarring effect artefact use-lives?

Answering each of these questions relating to artefact performance and the accurate identification of function in the archaeological record, this thesis seeks to establish a greater understanding of the relationship between artefact morphology and use by explaining some of the functional causes of formal variability. These results should, in turn, facilitate a level of understanding of how, and in what capacity, an artefact can be altered in order to maximise particular aspects of functional and behavioural efficiency within prehistoric hunter-gatherer subsistence strategies.

Experimental Design

In order to ensure statistical validity the experimental program conducted in this thesis was designed by Dr Ann Cowling, head of the Statistical Consultancy Unit at the Australian National University. Dr Cowling recommended a randomised block design in which completing only one replicate was necessary to achieve statistical validity. **Blocking** is an analytical strategy designed to eliminate noise produced by ‘nuisance factors’ (Tobias and Trutna 2006) associated with all experimental procedures. In the experimental program
outlined here, nuisance factors are likely to have included subtle differences in the moisture contents of the contact materials worked due to daily fluctuations in working conditions — such as the temperature or humidity at the time of experimentation. Blocking removes the effects of some of these variables by dividing the experiments into homogenous blocks in which nuisance factors are held constant and only experimental variables are allowed to vary. This means that within each block, the effects of the different variables being tested may be identified without concern for introduced variation due to changes of the block factors (Tobias and Trunta 2006). Each treatment, or level of variable (variables tested are listed in detail below), appears once in each block and the same number of all treatments is tested in order to remove any bias which may arise from the unfair dominance of some treatments in experimental programs (Dey 1986; Cox and Reid 2000). The number of blocks included in the design therefore relates to the number of replicates undertaken for each experiment. Randomisation determines the order in which each treatment (i.e. edge angle, edge plan etc) is tested within each block, in order to reduce the contaminating effects of nuisance factors (Dey 1986:1, Rasch and Herendorfer 1986; Tobias and Trunta 2006). In the experimental program carried out for this thesis, each combination of edge plan (concave, convex and straight), edge profile (concave, convex and straight), action (sawing, scraping), contact angle relevant to action (high, low, vertical), edge angle (high, low) and contact material (hard, soft) appeared once in each of the two blocks deemed necessary to achieve statistical validity. For example, only one artefact with a concave edge plan, convex profile, and low edge angle would be used to scrape soft wood at a high contact angle in each of the two blocks of experiments. The first block was completed before the second block in order to ensure that environmental factors were as consistent as possible within each block. The order in which each combination of edge angle, edge plan, edge profile etc. was tested was randomly assigned within each block and experiments were conducted in accordance with the order listed in the design. This experimental design ensured the equal and unbiased treatment of all variables being tested.

The time consuming nature of wear analyses of polishes and striations and requirements of high powered microscopes (100-200x) with vertical incident lighting meant that these types of wear could not be adequately explored in addition to other goals within this thesis. However, the ability to observe the presence or absence of scars and their relevant properties at comparatively much lower magnifications (10x-30x) and in shorter periods of time, meant that edge scarring could be used as a representative of wear and more easily be tested in conjunction with investigations into artefact performance. As such, scarring is the only form of wear explored within this thesis. Given that all forms of wear are argued to
be the product of use action and contact material, the results of investigations into the
development of edge scarring will necessarily have important, though unquantified,
implications for other forms use wear also.

Variables

A number of variables have been identified in the literature to impact upon artefact
performance and the development of wear. These may be divided according to
technological components and are detailed in table 2 below.

Table 2. Variables identified to impact upon stone artefact performance and the development of
wear according to technological component.

<table>
<thead>
<tr>
<th>Working edge:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle</td>
<td></td>
</tr>
<tr>
<td>Shape in plan</td>
<td></td>
</tr>
<tr>
<td>Shape in profile</td>
<td></td>
</tr>
<tr>
<td>Shape of aspects in section</td>
<td></td>
</tr>
<tr>
<td>Contact edge length</td>
<td></td>
</tr>
<tr>
<td>Raw material:</td>
<td>Type</td>
</tr>
<tr>
<td>Use:</td>
<td>Motion: longitudinal, transverse, vertical, impact</td>
</tr>
<tr>
<td></td>
<td>Speed of stroke</td>
</tr>
<tr>
<td></td>
<td>Length of stroke</td>
</tr>
<tr>
<td></td>
<td>Use duration</td>
</tr>
<tr>
<td></td>
<td>Pressure applied</td>
</tr>
<tr>
<td>Contact material:</td>
<td>Type</td>
</tr>
<tr>
<td></td>
<td>State</td>
</tr>
<tr>
<td>Skill of the Experimenter</td>
<td></td>
</tr>
</tbody>
</table>

Within each of these variables exists a wide range of testable units. Edge-angle, relief-angle
stroke length and speed, use pressure, use duration and contact material state all represent
continuous variables, and therefore offer an infinite number of units to test. Edge plan,
shape, profile and aspect shape range from four to six combinations each. Likewise, raw
material and contact material have as many possibilities as there are suitable materials to use
and work. As such, the selection of variables and units of measurement for testing had to
be limited to what could be reasonably and adequately tested within the time constraints of
doctoral research.

The range of available measurable units within each of these variables meant that arbitrary
decisions regarding what would be tested had to be made. It was therefore decided that
where possible, two measurable extremes of each variable would be tested.

- The following variables remained constant in all experiments conducted:
  - Raw material – Brandon flint
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- Force – 4kgs
- Contact surface – ventral (see figure 5)
- Speed – 16 strokes/min
- Stroke length – 20cm
- Duration – strokes 100x, 200x and at 200x intervals up to 2400x

The following variables were systematically varied and tested in accordance with the statistically derived experimental program (the variables plan and profile are illustrated in Figure 1, pg 33 while edge and relief-angle are illustrated in Figure 5):

- Contact Material – hard wood (Merbau) and soft wood (Baltic Pine)
- Relief-angle – high (30 degrees) and low (15 degrees)
- Edge-angle – high (60-65 degrees) and low (20-25 degrees)
- Action – sawing (bidirectional), Scraping (unidirectional)
- Edge plan – straight, concave, convex
- Edge longitudinal profile – straight, concave, convex

The following variables were measured and monitored throughout experimentation but could not be controlled for due to the variation each:

- Artefact size
- Artefact weight
- Extent of curvature of concavity/convexity in both profiles

Specimens for experimentation were selected according to those features being varied or controlled in each experimental run. All experiments were conducted on unretouched, decorticated flakes made of Brandon Flint which, along with force, speed, contact surface and stroke length, was held constant throughout. These specimens were obtained courtesy of Mr Tom Fuller, a master flint knapper based in England’s Lakes District, who flaked thousands of specimens for me and assisted in their shipment to Australia.

Flint was chosen for a number of reasons, the first being that flint is one of the most widely used raw materials in archaeological assemblages throughout the world, and has been particularly heavily utilised in the Americas and across Europe (Sevillano 1997). The
proliferation of flint in archaeological assemblages worldwide gave wider relevance to any results that could be gleaned from experimental investigations using this material. Secondly, the popularity of flint as a medium for the manufacture of flaked stone tools has been explained as a product of its superior flaking properties. A variety of chalcedony, flint is highly silicious in content, with a homogenous and microcrystalline structure (Dománski et al. 1994; Sevillano 1997; Dománski and Webb 2000). The uniformity of flint’s microcrystalline structure is such that it lacks any ‘direction-dependent properties’ that may interfere with the fracture path of a flake during knapping, with ‘flake detachment [is] determined only by the stress distribution during the flaking event’ allowing it to be ‘more readily controlled by the knapper’ (Cotterell and Kamminga 1987; Crabtree 1968) (Webb and Dománski 2000:822). The value of these properties of flint was two fold for the purposes of the experimental program conducted. Firstly, the fine grained homogeneity of flint means that flakes produced bear extremely sharp edges with strong holding properties; both of which might be considered advantageous to functional efficiency in stone artefacts. Secondly features of conchoidal fracture and scarring produced through use actions are particularly clear on such fine grained homogenous material, making any macro- and microscopic wear generated easier to see and quantify. A large degree of internal variation exists within the broad class of ‘flint,’ with differences noted in microstructures, flaking properties and fracture toughness between types (Dománski and Webb 2000). As such, in order to keep raw material a constant throughout experimentation, all specimens were manufactured from flint from the same area of the Brandon flint mine.
Merbau and Baltic Pine were chosen for several of reasons. Limitations existed in the range of contact materials able to be tested, due to the need to hold contact material steady in the machine’s vice. In addition, the requirement of applying a constant force to all actions meant that both contact materials needed to be able to withstand the same amount of force; rather than comparing contact materials such as yam which would require extremely light pressure, with something like wood or bone in which a greater downward force would be required. It was therefore decided that two types of wood, of differing hardness, would provide as wide a contrast in material hardness as was possible whilst accommodating the limitations of the machine. In order to limit the amount of variation introduced by using two different species of woods, with different moisture contents, different ages etc, it was important that the treatment each wood type received was known and was comparable. Merbau and Baltic Pine fit these requirements for the following reasons.

Wood hardness is commonly tested for commercial use using the Janka hardness test (Doyle and Walker 1985; Hirata et al. 2001). The forces required to embed a steel ball, which measures 0.444 inch, to half its diameter in the wood are used to indicate the wood’s hardness and are expressed numerically relative to pounds per square inch (psi). The more easily the ball is able to penetrate the wood, the softer the wood is regarded. Merbau is one of the hardest, readily obtainable, woods in Australia, with a Janka hardness of 2230psi. The species originated in Indonesia, but now also grows in the Indo-Malayan region, South East Asia, as well as some areas of Australia (Queensland Government 1996-2006; Timber Development Association 2006). It is a straight grained wood with an even but coarse texture. By comparison, Baltic Pine is a soft wood, with a janka hardness of 210psi (Australian Timber Importers Federation 2006). Baltic Pine is widely distributed throughout Europe, Scandinavia and Britain and is regularly imported into Australia (Australian Timber Importers Federation 2006). While small knots are quite common in Baltic Pine, pieces with minimal knots were chosen for experimentation. Both these wood types were obtained from Canberra timber dealers who ensured that the two woods used had received the same treatment – both had been kiln dried for export, chemical treated to meet quarantine standards and retained a moisture content of between 12 and 14%.

Edge angles were measured at three points along the working edge using a goniometer, two millimetres from the working edge. Edge angles were required to fall within the 5 degree range of each of the 20-25 or 60-65 degree categories at each of the three points measured, for the edge to be included in the experimental program.
The Equipment

Mechanisation

In order to maintain internal validity, by ensuring that experimentation was systematic and controlled, all extraneous or potentially confounding variables and the ability to hold constant as many variables as possible was necessary. While variables such as edge shape, edge-angle and raw material could be readily controlled by selecting specimens for the relevant characteristics, enormous difficulty occurs in holding constant use-related variables such as force, edge-angle, relief-angle and stroke length in any manual operation. Mechanisation, however, would allow maximum control of each of these.

The relative advantages of mechanising various activities have been noted by a number of archaeologists (Kamminga 1982; Hurcombe 1992), but are argued to be offset by a number of disadvantages, the primary objection being that mentioned above - failure to produce ‘realistic’ patterns of wear likely to occur in archaeological contexts. However, if experiments are never undertaken to isolate variables adequately it may never be possible to understand why variations exist between implements due to the potential of many different combinations of variables causing them. It therefore seems that two complimentary approaches are required. Controlled experimental studies are needed first, to test hypotheses and properly isolate cause and effect relationships between as many variables as possible. Subsequent studies are then necessary to test these ideas against the archaeological record and bridge the gap between laboratory theory and archaeological reality. This thesis deals only with the first of these, by controlling and isolating the effects of plan, profile, edge-angle and relief-angle on the development of wear and performance of scraping and sawing activities on wood.

The wide range of variables to be controlled and tested required that any machine used be flexible in terms of the range of angles, actions, speeds and pressure able to be controlled. In the absence of machines currently available to perform such tasks, the Department of Engineering at the Australian National University was commissioned to produce a prototype machine, purpose built for testing longitudinal and transverse motions. Initial costings for the manufacture of the machine proved prohibitive and a compromise was finally reached by modifying a pre-existing machine.

An old shaping machine – the ‘Butler 26 inch supercrank’ – used previously to shape and turn metal – provided a basic back and forth motion (see Figure 6). Manufactured in 1951
by the Butler Machine Tool Company Ltd, the shaper has continued to be maintained and used by members of the Australian National University's mechanical workshop and was in perfect working order. Already programmed into the machine was the ability to control the length and speed of the stroke and an inbuilt feed mechanism on the table which allowed any contact material attached to the table to be moved along at any chosen increment, always providing a fresh workable surface for the implement. Modifications were required to create a holding device for the artefacts themselves (see Figure 7) and to enable control over the relief-angle at which the artefact was held to the worked material, the downwards pressure on the artefact and the angle of the artefact according to transverse or longitudinal motion. This was done by attaching a steel head to the supercrank, which comprised two pneumatic cylinders encased in steel and bracketed to a steel plate. The cylinders provided the ability to apply either constant or intermittent pressure to the artefact, with one acting to lift the device away from the contact material, and the other returning it. This allowed both uni-directional and bi-directional contact between the artefact and contact material. In scraping experiments, pressure was applied uni-directionally in a transverse motion, with the artefact lifting from the material at the end of each stroke and making contact again at the beginning of the next stroke.

Figure 6. The Butler 26" supercrank. Built by the Butler Machine Tool Company Ltd. 1951, England.
Comparatively, in sawing experiments, pressure was applied bi-directionally in a longitudinal motion, with the artefact remaining in constant contact with the same stretch of material in both backward and forward strokes. The cylinders also controlled the amount of pressure applied during use, which was held constant at 4kg throughout the experimental program.

Attached to the base of the cylinders was a second small, rotatable holding device with a 20mm groove into which the prepared artefacts in their aluminium casings could be slid (see following discussion on specimen preparation and photograph in Figure 8). This groove allowed artefacts to be repeatedly removed and replaced to the exactly the same position, ensuring that the same contact area was worked each time. In addition, the holder could be adjusted to maintain any relief-angle required (see figure 9).

The up and down motion provided by the pneumatic cylinders was controlled electronically through the use of an electronic control panel, photographed in Figure 10. This panel allowed me to dictate the amount of pressure applied to the artefact, whether or not it was to be constant (bi-directional) or intermittent (uni-directional), the number of strokes required and the number of strokes already carried out in that particular run. Information was fed from the machine to the panel via trigger switches which were
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Figure 8. Fastening artefacts into specially manufactured holding device to ensure artefacts were in an identical position for the entire experimental run.

Figure 9. Adjusting the rotatable head to obtain desired relief angle.
attached to either end of the machine's existing backward and forward movement. As the shaper carried out its backward and forward stroke, contact was made with the electronic triggers, feeding the counter and ensuring that the point at which the head lifted and released was the same for each stroke. This meant that a specific number of strokes could be set, each at the specified length of 20cm, and with a certain amount of pressure. When the number of strokes had been carried out, the head automatically lifted releasing contact between the artefact and the material. More specific mechanical details of the machine are currently being prepared for publication in an engineering volume (Gresham et al. In Press).

The use of this machine meant that the crucial variables of stroke length, stroke speed, pressure, use action, relief-angle and extent and direction of contact could all be held constant or varied at will. This level of control over both extraneous and relevant variables has never been achieved in experimental use studies before.

Scales

For every experiment, weights were taken for both the artefact and contact material at the beginning and end of every 100 or 200 stroke use episode. Quantities of material loss to
both the artefact and contact material were recorded in order to facilitate comparisons between the performances of different variables. To achieve as high a level of accuracy as possible, a set of Mettler AJ 100 scales were used, which have an accuracy of +/- 0.0001g and carry a maximum weight of 105 grams.

**Specimen Preparation**

In order for the machine head to be able to hold all artefacts, regardless of irregularities in shape and size, specimens were glued into universal size aluminium channelling which slid into the mount on the mechanised head. After being weighed and measured for all relevant features, the specimens were glued into channelling using a two part, 24 hour drying epoxy. The channelling meant that not only could almost any artefact size and shape could be held in the machine but also it reinforced the ability to allow specimens to be removed for weighing after each use episode and returned to exactly the same position.

**Recording Edge Scarring**

Prior to use, all working edges were scanned to ensure that any pre-existing edge damage was either not present or minimal. Any scars existing on the edges of artefacts prior to experimentation were recorded, though every effort was made to ensure that edges were fresh and undamaged. Scars were counted and their features recorded at the end of every use run, be it 100 or 200 strokes, and all relevant features were recorded. The following features were recorded for each individual scar:

- Duration in which the scar occurred
- Size (length mm) < 1mm Very Small
  - 1-2mm Small
  - 2-3mm Medium
  - 3-5mm Large
  - > 5mm Very Large
- Orientation – dorsal to ventral or ventral to dorsal
- Initiation type – hertzian, bending or snap
- Termination type – feather, step, hinge or snap
Measuring Performance

The mechanisation of use in this experimental program meant that pressure, speed of stroke and length of stroke were all held constant. As such, in scraping experiments, performance could comprise a simple measure of the amount of material removed by the edge in each particular run of either 100 (in the first 200 strokes of use) or 200 stroke intervals. In sawing experiments, the goal of activity is generally believed to be to cut through an object or to deeply groove it. As such, both material loss and depth of cut were measured. However, depth of cut was regarded as the primary indicator of performance. Material loss for a single 200 stroke run in a scraping experiment is photographed in Figure 11.

For the purposes of analysis, the activities of scraping and sawing are separated in this thesis. Differences in the motions used, relief-angles, pressure types and goals of each action meant that direct comparisons between them are difficult and different measures of effectiveness are necessary.

Figure 11. Material removed from a 200 stroke run, scraping hard wood.
Measuring Longevity

The long term productivity of an edge was estimated by how well it performed over time. For consistency, all artefacts were used for a minimum of 1200 strokes regardless of how effective the edge was throughout that period. However, in order to record the long-term usability of particular edges, an arbitrarily defined minimum performance level was established, beyond which it was thought that continued use of the edge would produce unsatisfactory material loss for the time and effort expended. Edges which failed to produce less than half a gram of material loss at the end of each of three successive runs of 200 strokes ceased to be used. Those artefacts that continued to be used for the entire 2400 stroke run were those with the greatest ability to maintain their level of performance over longer term use.

Limitations

Analysis of the impact of longitudinal profile on longitudinal actions proved difficult in this study due to restrictions placed on experimentation by the machine used to conduct them. While it is supposed that, in some cases, the aim of longitudinal actions would be to cut through a piece of wood, this was not possible using the machine. The nature of the set-up meant that if any piece of wood was cut through entirely, the head of the machine would be thrust into the metal vice below and could be ripped from the base of the machine.

A second problem arose in preliminary experimental runs which sought to identify any problems that might arise with the machine prior to beginning experimentation. Initial experiments proceeded by allowing all strokes used in longitudinal actions to be performed in the same groove. However, following the performance of some 400-600 strokes, material loss diminished rapidly with the edge of the artefact simply rubbing over the top of the groove. Performance plummeted and the edge seemed exhausted. However, when that same edge was placed on a fresh surface, productivity immediately returned to the levels attained in the first 50 or 60 strokes of the run. After searching for a number of explanations for this phenomenon it became clear that the relationship between force and contact area was responsible (see figure 12). As the cut created deepened, more of the working edge came in contact with the material, including larger areas of both edge aspects. This meant that the pressure impacting upon the edge itself was substantially decreased, with the force applied to the tool being distributed over a much larger contact area. As such, the constant force applied to the working edge was insufficient to allow the larger area to continue to perform at the same level. In order for the edge to continue to perform...
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Figure 12. Schematic diagram of the effects of increased penetration on the contact area of the edge in sawing activities. Increased penetration increased the areas of contact along the edge creating a greater distance over which to divide constant force applied. As such, as contact area increased, the pressure applied to the edge decreased, diminishing the ability of the edge to cut.

at the same rate and for the initial pressure placed on the tool to be maintained throughout the use cycle, the force applied would need to be increased in proportion with increasing artefact contact area. As force is one of the variables held constant in this experimental program, an alternative means of keeping pressure on the edge and contact areas constant was necessary. It was therefore decided that a fresh surface would be provided after every 10 strokes. While this approach solved the problems outlined above, it meant the working edges had little chance of being very deeply embedded in the wood, thus limiting the effects of longitudinal profile and edge-angle upon groove depth and shape over the long term. For the purposes of generating grooves, rather than cutting through a piece, this experimental design posed no problem, allowing cumulative depths to record diminishing levels of artefact performance over time. It also allowed initial effects of edge-angle and profile to be recorded. Pressure therefore represents an area for future research, facilitating a greater understanding of the roles of profile and edge-angle as variables in sawing activities.

PREDICTED OUTCOMES AND IMPLICATIONS

The widespread dependence of archaeological interpretations upon assumptions of tool performance, suggests that the outcomes of this research will have important implications for future interpretations of stone artefacts. Minimally, three broad areas of artefact analysis are likely to be affected; the analytical frameworks through which individual artefacts are identified and interpreted the construction of broad scale behavioural models of technological change on the basis of assemblage composition and the use of wear analyses to interpret artefact function. These are discussed below in relation to each of the six potential outcomes identifiable from the experimental program outlined here.
Outcome 1. Unique relationships exist between scar frequency and patterning and use action and contact material.

If unique relationships can be found to exist between use and wear patterning, then many of the problems identified as affecting and limiting the identification of artefact functions in an archaeological context may be irrelevant. Current approaches to the construction of experimental programs must therefore be regarded as sufficient, and the variables that have been tested considered adequate, in order to allow the development of useful interpretive principles of wear. As such, interpretations based upon these experimental programs must be regarded as appropriate. This discovery would allow analysts to expand on current definitions and construct more broadly-based theories of hunter-gatherer behaviour rather than individuals needing to continually repeat experimental programs. In addition, the inability to identify problems with current systems of experiment and analysis would suggest that alternative sources of error must be sought for the acknowledged inconsistencies in the appearance of wear.

Outcome 2. Scar frequency and type cannot be found to be uniquely connected with use action or contact material.

If consistent correlations between use variables and scar type or frequency cannot be identified it must be acknowledged that our ability to identify the functions of stone artefacts from wear patterning is heavily flawed and our experimental protocol inadequate. If morphological features of the working edge can be shown to have an equal or greater impact upon the development of scars than variables, such as use motion or contact material, then current approaches to the construction of experimental programs and the definitions of wear developed from them must be revised. New experimental programs testing a larger number and wider range of both morphological and use related variables should be advocated and the results statistically verified in order gain a more accurate understanding of the circumstances under which wear develops and exactly what it represents when identified on archaeological specimens.

Outcome 3. Meaningful differences in the performance of different edges cannot be detected, irrespective of variation in the raw materials used, edge form, state or function.

If this is found to be the case then a number of issues relevant to current analytical frameworks must be re-evaluated. First, the concept that form and function are uniquely connected must be reconsidered. If any form is equally effective in performing any
function, then direct comparisons between form and function must be rejected. Likewise, if retouch is found to have little bearing on artefact performance, then retouched and unretouched forms must be regarded as functional equivalents. Different causes and meanings for retouch must be sought.

The current dependence upon assemblage structure and composition for the construction of behavioural and technological models is such that the discovery that all forms are equally effective would have drastic consequences for interpretation of lithic assemblages. If any form is found to be equally capable of performing any function, the presence or absence of specific implement types may become a poor indicator of site function.

Similarly, if the performance of individual artefacts is found to have little ability to alter efficiency, then factors other than function and performance must be conditioning artefact form. The extension of artefact use-life, mobility patterning and raw material procurement strategies will become increasingly important explanations of artefact and assemblage variation. Differences in assemblage composition between sites over time and space would therefore be more likely to represent responses by technological systems, rather than shifts in individual functional requirements. This would, in turn, suggest that technological adaptations to changing socio-ecological conditions operated at the level of entire systems rather than individual artefacts and greater attention should be focussed on the efficient organization of technological systems.

**Outcome 4. Functional differences are identified but equivalencies exist between particular forms.** Certain combinations of factors are found to perform the same tasks equally effectively.

A second possibility is that functional differences exist between forms, but that certain combinations of factors on morphologically dissimilar forms perform equally effectively in particular tasks. This implies that interrelationships exist between the relevant functional variables.

Interplay between edge variables has been noted by a handful of archaeologists. Moss (1983a) stresses the efficiency of an edge that is straight in plan over alternative concave or convex shaped edges, due to its resistance to edge damage. She notes that edge damage is likely to decrease productivity but that the increased damage incurred by curved edges can be offset by increasing the working edge-angle (Keeley 1980; Moss 1983a). Relief-angle during use is noted to have a similar capacity for offsetting edge damage. By adjusting the relief-angle, and therefore the location of the tensile and compressive stresses within the
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artefact, the types and frequencies of edge damage resulting from use will differ (e.g. Tringham et al. 1974; Keeley 1975). Edge shape, edge-angle and relief-angle represent only three of a wide range of variables with the potential to impact upon artefact performance and durability, while also affecting implement form.

To date, analyses into the morphological differences and similarities of implements used to perform identical functions, have been entirely absent. Yet these interrelationships have important implications for artefact analysis. If it may be shown possible to offset weakness in one variable through change in another, it may also be possible that a number of different combinations of edge-angle, edge shape and relief-angle acted as functionally effective equivalents. This would mean that assemblages that appear to be diverse in the number of forms present may, in reality, be quite restricted in the range of functions represented. This would necessarily complicate assessments made on the basis of assemblage composition and diversity, requiring that archaeologists recognise equivalent forms and functions before artefact assemblages can be interpreted.

Outcome 5. Certain combinations of characteristics are found to be more effective in performing particular tasks.

A third possibility is that particular combinations of morphological features perform substantially better than others in specific tasks. This would have important implications for essentialist typological approaches to artefact analysis which consider artefact form to be distinctively associated with implement function. The existence of task specific, high performing forms would provide a unique opportunity to test typological ideas by comparing noted high performing combinations of features with the 'ideal' types defined by typologists.

The existence of highly effective artefact forms would further allow archaeologists to test the assumption that implement performance is a driving mechanism in the production and use of prehistoric stone artefacts. The ability of particular combinations of features to enhance performance and productivity would suggest that, where possible, we would expect such forms to be heavily utilized in their suited tasks in the archaeological record. In situations where discrepancies exist between expected high performing forms and archaeological specimens, these differences may provide some indication of the types of additional pressures that may have been placed on the technology in that particular circumstance. Alternatively, the inability to reconcile differences between expected and
observed morphologies, through the exploration of additional factors, may indicate one of two possible outcomes: that it is efficiency in the organisation of the technological system, rather than in individual artefacts that hunter-gatherers strive for, or that implement performance and technological efficiency should be given lesser interpretive value than is currently advocated in archaeological interpretation.

Outcome 6. Highly effective forms exist and retouched and unretouched forms perform in exactly the same manner.

This outcome is perhaps best viewed as an extension of outcome three and suggests that, if it is possible to identify high performing combinations of features on unretouched edges, it is probable that, provided the relevant characteristics are present, it makes little difference whether or not the edge has been retouched. Two possible outcomes exist for the effect of retouch on function; retouch returns the edge to its original performance levels and the same task can continue to be performed, or retouch alters the ability of the edge to perform in that same function and, instead, increases its ability to perform alternative activities. Because the process of retouch involves adjustments to the shape, size and state of the working edge, it is possible that as retouch progressively reduces the artefact and changes the qualities of the working edge, it will also progressively alter the functions for which each new edge would be best suited, as was discussed in Chapter 3 (see also Figure 4 pg 59). If this is the case, important archaeological implications arise for current analytical frameworks.

Returning to the essentialist typological belief that artefact forms represent the knapper's ideal form for a specific function, then an artefact's function should not change throughout its use-life. This means an 'ideal' form must be manufactured for each and every function and discarded when it no longer performs that function. It further demands very high artefact replacement rates, attracting prohibitively high labour costs (inputs) by requiring large numbers of raw materials and implements to be carried and manufactured, in case a particular need arises. If it can be shown that retouch simply changes the function for which the working edge is best suited, it would make more sense to suggest that, as an artefact was used and the edge was rejuvenated through retouch, the functions to which it was put changed accordingly, with one artefact performing many different functions throughout its life.
Regardless which of these outcomes may be shown to hold true, the enormous potential of such an investigation to challenge current ideas and enhance our understanding of prehistoric hunter-gatherer behaviour is clear.

DISCUSSION

It is clear from the discussion presented in this chapter than the experimental program conducted in this thesis has been conducted using the highest possible level of control over as wide a range and number of variables as was possible, within the confines of the research. Avoiding the problems identified with previous experimental investigations into artefact function and incorporating observations made by previous analysts, this program is intended to contribute to, and build upon, preceding research. In addition, this research has provided the first, of what is hoped will become many, investigations into artefact performance. It has the potential to shift current perceptions about the technological and broader level subsistence behaviours of prehistoric hunter-gatherers. The results of the experimental program outlined here are presented in the following chapters and begins with an exploration of the relationship between scar patterning and specific aspects of artefact use.
CHAPTER 7

SCARRING AND USE-WEAR – EXPERIMENTAL RESULTS

INTRODUCTION

The discussion in Chapter 2 detailed the types of wear commonly used by analysts to interpret stone artefact function; polish, striations, abrasion and edge-scarring. In this thesis, edge-scarring alone is explored in relation to the range of morphological and use variables tested by the experimental program in the previous chapter, in order to explore the question: How robust are the principles of use-wear? Function is defined in the use-wear literature by the motion in which the artefact was involved and the relative hardness of the material worked, each of which is argued to be indicated by variations in the scar patterning produced through use. Wear analysts rely not only on the presence or absence of scarring, but also on the frequencies of individual scar features such as orientation, initiation, termination and size to construct interpretations of artefact function. Statistical analyses conducted and discussed in this chapter test the idea that particular scar features are distinctive of use by identifying which variables make the greatest contribution to the frequency and appearance of scars on a working edge from use.

EDGE-SCARRING FEATURES

Edge-scarring occurs through use when the force exerted on the working edge exceeds that which the raw material of the artefact is capable of absorbing, resulting in the fracturing of flakes from the working edge. An extensive body of literature exists on the development of edge-scarring and the forces involved (e.g. Crabtree 1972; Speth 1972; Hayden and Kamminga 1973; Cotterell and Kamminga 1979, 1986, 1987; Tommenchuk 1988a, 1997; Domanski et al. 1994; Pekin 1997a). However for the purposes of this thesis, it is the nature and number of the scars developed, rather than cause of scarring, which is of interest.

Wear analysts commonly refer to four different scar features for the interpretation of edge function; initiation type, scar size, scar orientation and termination type (e.g. Tringham et al. 1974; Odell 1980; Lewenstein 1981; Kamminga 1982; Akoshima 1987; Cotterell and Kamminga 1987; Shea and Klenck 1993). Hertzian initiations, or conchoidal fractures, are argued to occur when force is applied to a single point (e.g Crabtree 1972; Speth 1972;
Hayden and Kamminga 1973; Cotterell and Kamminga 1979, 1986, 1987, Domanski et al. 1994; Pelcin 1997a), and result in the generation of a flake with a clear point of impact, hertzian cone/bulb of percussion and in some cases errailure scar and walner lines radiating from the point of impact (Cotterell and Kamminga 1979). The inverse of each of these features is left behind on the working edge in the form of a flake scar. By comparison, bending initiations are said to be the result of the division of force over a relatively larger area (Cotterell and Kamminga 1979; Kamminga 1982). As force increases, flakes with a small lip where the ventral surface meets the platform are generated, for which no clear point of impact exists. Along a working edge, scars initiated by bending forces can be recognised by crescent shaped grooves where the scar has been initiated. In this experimental program, length was used as the measure of scar size. Orientation is recorded in relation to which face of the working edge the scar creating force is initiated from; either the dorsal or ventral face. For example, scars initiated from the ventral surface radiate onto the dorsal surface and are therefore described as ventral-dorsal orientated. Those initiated from the dorsal surface are recorded as dorsal-ventral with scars initiated from the dorsal surface emanating onto the ventral surface. Scar termination type is thought to be subject to the amount of force exerted (Cotterell and Kamminga 1979) relative to the fracture properties of the raw stone material being used, the orientation of the tool to the material worked and the geometry of the edge’s contact surfaces (Kamminga 1982:5). Depending upon the force applied, a flake may incur a feather, step or snap termination through use. Feather terminations are argued to occur when the amount and direction of force applied is sufficient to allow the fracture to initiate and complete its path to a gradual termination (see figure 13a) (Cotterell and Kamminga 1979:104-105). Step terminations (see figure 13b and c) are argued to occur either when the fracture runs into an internal flaw in the raw material and terminates abruptly, or where the fracture path continues its journey but the flake snaps at some point along its length (Cotterell and Kamminga 1979; Macgregor 2001). Snap terminations (see figure 13d) are most commonly associated with low edge-angles, and result from the transverse snapping of the working edge (Crabtree 1972; Cotterell and Kamminga 1979; Kamminga 1982).

In order to test the existence of a relationship between each of these scar features and use, a series of statistical analyses were conducted, designed to identify the effects of both use and morphological variables upon the development and appearance of scars. The scar features (orientation, initiation, termination and size) have different numbers of descriptors in each case. A total of 708 scars were recorded from the 108 artefacts involved in the experimental program. Of these, 488 arose during scraping activities and 220 during
sawing activities. Each scar was classified by orientation, initiation, size and termination. The morphology and usage variables affecting each scar classification variable were identified by fitting multinomial models to the data.

Multinomial models are relevant in situations where multiple causes may contribute to a single event. They are therefore appropriate when the response variable is categorical with
more than 2 classes and facilitate an estimation of the independent contribution of each possible cause (Cox 1972; Small and Hsiao 1985). In the following analysis of scar features, multinomial models were used to generate predictions of the probability of a scar resulting in a particular type of initiation, orientation, size and termination type as an independent effect of each of the use-related variables tested in the experimental program - edge-plan, edge-profile, edge-angle, contact-angle and contact material for both sawing and scraping actions. The predicted effects of all two-way interactions between use-related variables upon the frequencies of each scar feature were also identified. Statistics were run using the 'R' program for statistical computing (Leisch 2003) which is capable of a wide range of statistical and graphical techniques (http://www.r-project.org/) and is the chosen method of statistical analysis by the Statistical Consultancy Unit, Australian National University. In each analysis presented below, the null hypothesis tested was that no interaction existed between variables that could affect the frequencies of scar orientation, termination, initiation and size incurred through tool use. The p-values listed at the beginning of each section relate to the probability that the null hypothesis is true. The lower the p-value for any interaction, the lower the probability that the data collected could have been generated if no difference existed. If no interaction exists between variables tested, it would not have been possible to generate the data that was generated. It is therefore possible to reject the null hypothesis and conclude that the lower the p-value the greater the probability that an interaction exists between the tested variables. P-values that are less than 0.05 are regarded as being statistically significant (Drennan 1996).

For each of the scar features discussed in this chapter there exist multiple statistically significant variables and interactions between relevant variables affecting the proportions of that feature incurred by edges through use. As a consequence, the effect of any one variable on the proportions of a scar feature must be considered, in combination with the effects of other significant variables or interactions. To clarify the effects of each individual variable and interactions on each scar features, the following discussion outlines the effects of each interaction individually, graphing the effect of that specific interaction 'all else being equal'. In each of the figures below, lines have been drawn between values of the same variables. They do not indicate that intermediate measures exist between markers. Below each figure is stated the level of other relevant variables which have been held constant in order to illustrate the specific interaction being discussed. Also included is a list of the predicted ranges of proportions of that feature and interaction if 'all things are not equal,' enabling the levels of additional interacting variables differ. These lists indicate the range of proportions of a particular feature an analyst might observe, on a particular
functional edge, given the particular morphological features of the edge being analysed. All figures below represent predicted proportions of features for a given interaction 'all else being equal'.

**SCAR ORIENTATION**

Scar orientation is one of the most commonly used indicators of use-action in the use-wear literature (e.g. Tringham 1971; Tsirk 1979; Anderson 1980; Odell 1980, 1981; Dumont 1982; Kamminga 1982; Fullagar 1986; Akoshima 1987; Tomenchuk 1988; van Gijn 1990; Shea 1992; Shea and Klenck 1993; Alvarez et al. 2001). Because scarring occurs through use when force is applied to the working edge, scar orientation is argued reflect the direction of that force. Scars initiated from a single surface of the working edge are therefore argued to have been involved in transverse activities such as scraping and planning, in which only a single aspect of the working edge is in contact with the material. Scars initiated from both aspects of the working edge are therefore argued to have been involved in longitudinal use-actions in which both aspects of the working edge are in contact with the worked material, such sawing or cutting actions. The results presented below indicate that the causes of scar orientation are more complex than has been assumed by previous explanations.

**Scraping**

A total of 478 scars were removed during use in scraping activities. Of these, scars 238 were initiated from the dorsal surface and 240 were initiated from the ventral surface. In all scraping experiments, the ventral surface of the flake faced the contact material. Listed in order of their probability values, the multinomial models identified the following variables and interactions as having a significant effect on scar orientation from the data:

1. Relief-angle (p<0.001)
2. Edge-angle (p=0.029)
3. The interaction between longitudinal profile and contact material (p=0.0031)
4. The interaction between plan and contact material (p=0.004)
Relief-angle \((p<0.001)\)

There was a highly significant effect of relief-angle on scar orientation, in which low relief-angles are found to consistently sustain higher levels of scars initiating from the ventral surface (V-D) than high relief-angles (see Figure 14). For any combination of the other factors (i.e. edge plan, profile, edge-angle etc), the proportion of V-D scars is predicted to be higher for low relief-angles. However variation in other factors leads to a range in the proportion of ventral to dorsal scars, which represent 28-93% of all scars sustained. In the case of high relief-angles, the range of proportions of V-D scars is anywhere between 14 and 86% of all scars incurred, depending upon the values of other relevant features.

![Figure 14. Effect of Relief-angle on the predicted proportion of V-D orientated scars when scraping.](Image)

These results indicate that relief-angle may be responsible for a high degree of variability in the proportions of scars with V-D orientations which appear on edges used in scraping activities. This suggests that, in addition to interpreting the contact material and action responsible for generating scar patterning, analysts must also take into account the wide degree of variability that may have been caused by using different relief-angles.

Edge-angle \((p=0.029)\)

Scar orientations were found to differ significantly with edge-angle, with high edge-angles sustaining a higher proportion of V-D orientated scars than low edge-angles (see Figure 15). However, while a greater proportion of scars of this orientation is predicted to occur with high edge-angles for all combinations of plan, profile, edge-angle and contact material, the range in the proportion of scars that are V-D orientated will again be dependent upon the levels of other relevant variables. As such, the predicted proportion
of V-D scars incurred by high edge-angles ranges between 20 and 93%. The predicted proportion of V-D scars obtained by low edge-angles ranges between 14 and 90%, slightly lower than that of high edge-angles.

![Graph showing the effect of edge-angle on the predicted proportion of V-D orientated scars when scraping.](image)

**Figure 15. Effect of Edge-angle on the predicted proportion of V-D orientated scars when scraping**
(Levels of other terms: Plan – Concave, Profile – Concave, ReliefAngle – High, CM – Hard).

**Longitudinal Profile and Contact Material (p=0.0031)**

The interaction identified between longitudinal profile and contact material on scar orientation was found to be similar to that of plan, with profiles predicted to incur significantly fewer ventral to dorsal scars on soft wood than on hard. On soft woods, convex profiles are predicted to incur proportionately more V-D orientated scars than either concave or straight (see Figure 16). All profiles act differently on hard woods, with straight profiles predicted to sustain higher numbers of V-D scars than either concave or convex profiles. However, once again, the range of scarring is large, fluctuating according to additional relevant variables.

The ranges in predicted frequencies of V-D orientated scars for each combination of profile and contact material and incorporating the effects of different levels of the other relevant variables are as follows:

- Concave/hard – 29-92%
- Convex/hard – 24-92%
- Straight/hard – 34-94%
- Concave/soft – 14-42%
- Convex/soft – 37-73%
- Straight/soft – 17-49%
Figure 16. Effect of interaction between Profile and Contact Material on the predicted proportion of V-D orientated scars when scraping (Levels of other terms: Profile – Concave, Edge-angle – High, Relief-angle – High)

This interaction between profile and contact material on scar orientation frequency means that in order for analysts to know what the effect of the profile being analysed has had on observable frequencies of scar orientations, they must first know the contact material upon which it was used. These results suggest that contrary to indicating contact material, interpretations of scar orientations are instead reliant upon the analyst knowing the contact material worked, from the outset.

Edge Plan and Contact Material (p=0.004)

The interaction between edge plan and contact material was found to have a statistically significant effect on scar orientations and is illustrated in Figure 17. In general, all edge plans are predicted to scar significantly lower proportions of V-D scars when used on soft wood than those used on hard wood. More specifically, greater numbers of V-D scars result on convex plans when used on hard wood than on soft. Concave plans are also predicted to sustain greater numbers of V-D scars on hard wood than on soft but also greater numbers than convex plans on hard wood. Very much greater proportions of V-D scars are predicted to occur on straight plans when used on hard wood than on soft, with straight plans sustaining higher proportions of V-D orientated scars than any other combination of plan and profile. This being said, the range of proportions of scar orientations is again large.
Figure 17. Effect of interaction between Plan and Contact Material on the predicted proportion of V-D orientated scars when scraping. (Levels of other terms: Plan – Concave, EAngle – High, ReliefAngle – High)

The predicted ranges for each combination of plan and contact material, incorporating the effects of additional relevant variables, for proportions of V-D orientated scars are as follows:

- Concave/hard – 50-80%
- Convex/hard – 25-66%
- Straight/hard – 70-93%
- Concave/soft – 14-70%
- Convex/soft – 13-70%
- Straight/soft – 15-72%

While certain combinations of functional and morphological variables can be consistently stated to incur greater numbers of V-D orientated scars than others, it is clear that these relationships are far more complex than previously thought. The existence of significant interactions between use and morphology related variables means that wear analysts, using scar orientation as an indicator of artefact function, must not only take each variable into account but also interactions between variables, in constructing interpretations of use. This task will be made even more difficult by the range of potential proportions of V-D orientated scars possible in any given situation, depending upon the values of other relevant variables. Subject to the combination of morphological and use variables involved, between 14 and 94% of the scars incurred by the edge may have a V-D orientation from scraping activities.

Sawing

Fewer variables were found to have an effect on scar orientation in sawing activities. The interaction between plan and longitudinal profile was found to have a statistically
significant effect (p<0.001) upon frequencies of V-D orientated scars (see Figure 18). In general, convex profiles are predicted to attain higher levels of V-D scars except where plan is straight. Concave profiles are predicted to attain the lowest levels of V-D scars except where plan is also concave. Straight profiles, however, differ dramatically with each plan. Straight plan/profile combinations are predicted to produce approximately even numbers of V-D orientated scar, with pressure being applied equally to both aspects of working edge. In contrast, where straight profiles are combined with concave plans, predicted proportions of V-D scars are approximately 70% as compared to the 33% predicted for convex plan/straight profile combinations.

![Predicted proportion of V-D scars](image)

**Figure 18.** Effect of interaction between Plan and Profile on the predicted proportion of V-D orientated scars when sawing (Levels of other terms: Edge-angle - High, Relief-angle - High, CM - Hard).

The lowest proportions of V-D orientated scars are predicted for plan/profile combinations of convex/concave, straight/concave and straight/convex, with none of these combinations attaining more than 24% of scars with that orientation. Conversely, between 71 and 79% of scars are predicted to emanate from the ventral surface on the plan/profile combinations concave/convex, convex/convex and concave/straight.

These differences in scar orientation frequencies may be explained by the changes which different plans and profiles have on the direction of force applied during use. In longitudinal motions, convex plans will receive most pressure on the ventral surface as the edge projects into the wood. The opposite is the case on concave profiles, with most pressure directed from the dorsal surface, causing flakes to orientate dorsal-ventrally. The effects of concavities or convexities in profile may be either magnified, or offset, by the introduction of plan shapes depending on which shape is used. Straight plans divide the force applied over a wider area and therefore substantially reduce the amount of pressure.
applied to a protruding profile. Conversely, where a convex plan is worked with a concave profile the reduced contact area increases the pressure applied on that edge and enhances the effect of the concave profile. The same is true, in reverse, with concave plans reducing the contact area of the edge, increasing the pressure of the applied force and enhancing the effect of edge profile.

The ranges in predicted frequencies for each plan and profile, incorporating the effects of other relevant variables, to sustain V-D orientated scars are outlined below:

<table>
<thead>
<tr>
<th>Plan</th>
<th>Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave: 44-71%</td>
<td>Concave: 14-44%</td>
</tr>
<tr>
<td>Convex: 14-79%</td>
<td>Convex: 24-79%</td>
</tr>
<tr>
<td>Straight: 23-54%</td>
<td>Straight: 33-71%</td>
</tr>
</tbody>
</table>

Inferences of Use from Scar Orientation

These results indicate that contrary to indicating the types of actions involved in removing scars through use, scar orientation is subject to a wide range of complex interactions between morphological and use related variables. The variables responsible for dictating the orientation of scars in scraping activities are different from those which affect scar orientation in sawing activities. Yet, importantly, the ranges of possible proportions of orientations identified for sawing fall well within those identified for artefacts used in scraping activities. The ability for additional variables to affect scar orientation frequencies means that scar orientation is a poor guide to use-action when interpreting stone artefact function.

SCAR INITIATION

Scar initiation type is generally used to differentiate the scarring removed through use from that produced through deliberate or spontaneous retouch (e.g. Tringham et al. 1974; Newcomer 1975, 1976; Cotterell and Kamminga 1979; Kamminga 1982). The product of a direct and concentrated blow at a single contact point, hertzian initiations are argued to be rare on scars produced through use. Instead, bending initiations, which occur when the force involved is divided over a wide area - such as the length of the working edge - are expected. However, the results presented below indicate that as with scar orientation, the types of initiations produced through use are responsive to a wider range of variables than have been previously accounted for.
Scraping

A total of 292 scars created from scraping activities had bending initiations; a further 179 scars had hertzian initiations and 17 scars were created by flakes that initiated with a snap. The large numbers of hertzian initiated scars produced through scraping activities suggest, of themselves, that use alone is an insufficient explanation of the causes of bending initiated scars. Four interactions between morphological and use related variables were found to affect the frequency of these different forms of scar initiation during use. Listed in order of their probability values these are:

1. Longitudinal profile and edge-angle (p<0.001)
2. Longitudinal profile and relief-angle (p=0.011)
3. Longitudinal profile and contact material (p=0.016)
4. Relief-angle and contact material (p=0.046)

**Longitudinal Profile and Edge-Angle (p<0.001)**

The highly significant effect of the interaction between longitudinal profile and edge-angle on the probability of bending initiated flakes being removed during use is illustrated in Figure 19 below. In all cases, low edge-angles are predicted to incur significantly greater proportions of bending initiations. This difference is most obvious with concave profiles and least obvious with straight profiles. Convex and concave profiles are predicted to sustain significantly greater proportions of bending scars than do straight profiles on low

![Figure 19](image.png)

**Figure 19.** Effect of interaction between Profile and Edge-angle on predicted bending initiation frequencies when scraping. (Levels of other effects: Relief-angle – High, Contact Material – Hard)
edge-angles. However, as with scar orientations, the proportions of bending initiations incurred by any edge will be dependent upon additional features of relevant variables. In this case the relevant variables comprise the use related variables of relief-angle and contact material.

The ranges in predicted proportions of bending initiations experienced by profile/edge-angle combinations depending upon relief-angle and contact material and incorporating the effects of other relevant variables are:

- Concave/High: 0
- Convex/High: 3-26%
- Straight/High: 28-57%
- Concave/Low: 55-91%
- Convex/Low: 63-94%
- Straight/Low: 62-86%

The proportion of bending initiated scars removed from a working edge during use is therefore dependent not only upon use itself, but also on the morphological properties of the working edge.

**Longitudinal Profile and Relief-Angle (p=0.011)**

The effect of relief-angle on the proportion of bending initiated scars, likely to be produced through use, differs with profile. On concave profiles, bending initiated scars are predicted to be more common when worked at a high relief-angle; while straight profiles are predicted to produce higher proportions of bending initiated scars when worked at a low relief-angle (see Figure 20.).

![Figure 20. Effect of interaction between Profile and Relief-angle on predicted bending initiation frequencies when scraping](Levels of other terms: Edge-angle - Low, Contact Material - Hard).
Straight profiles are predicted to result in similar proportions of bending initiated scars regardless of the relief-angle used. The ranges in predicted proportions of bending scars incurred by profile and edge-angle interactions and incorporating the effects of other relevant variables are as follows:

Concave/High: 0-97%  
Convex/High: 12-94%  
Straight/High: 28-76%  
Concave/Low: 0-75%  
Convex/Low: 3-93%  
Straight/Low: 53-86%

**Longitudinal Profile and Contact Material** (p=0.016)

The effect of longitudinal plan on the frequency of scars with bending initiations also differed with contact material (Figure 21). While straight profiles predicted to sustain lower proportions of bending initiated scars, they produce slightly larger proportions on softer wood than on hard. By comparison, convex profiles are predicted to sustain more bending initiated scars on hard wood than on soft and concave profiles incur similar proportions regardless of contact material hardness.

The predicted range of proportions of scars with bending initiations for different combinations of profile and contact material, and displaying the effects of other relevant variables, are as follows:

Concave/Hard: 0-97%  
Convex/Hard: 5-76%  
Straight/Hard: 11-70%  
Concave/Soft: 8-98%  
Convex/Soft: 12-96%  
Straight/Soft: 10-45%

![Graph](Figure 21. Effect of interaction between Profile and Contact Material on predicted bending initiation frequencies when scraping (Level of other terms: Edge-angle – Low, Relief-angle – High).)
Relief-Angle and Contact Material \( (p=0.046) \)

The interaction existing between relief-angle and contact material states that, where relief-angle is low, bending initiations are predicted to be more common on hard wood than on soft (see Figure 22). However, proportions of bending initiations are always higher when using a high relief-angle, regardless of material hardness.

Ranges of predicted proportions of bending initiations for relief-angle and contact material interactions and incorporating the effects of other relevant variables are:

- High/Hard: 0-94%
- Low/Hard: 0-93%
- High/Soft: 0-91%
- Low/Soft: 0-81%

![Graph showing predicted proportions of bending initiations vs. relief angle and contact material.](image)

**Figure 22.** Effect of interaction between Relief-angle and Contact Material on predicted bending initiation frequencies when scraping (Level of other terms: Edge-angle – Low, Profile – Concave).

Use alone is therefore insufficient to explain the development and frequencies of bending initiations on edges used in scraping activities, with profile, edge-angle, relief-angle and contact material each found to have differing effects on initiation type frequencies. Anywhere between 0 and 97% of the scars created on edges used to scrape wood, had bending initiations. As such, between 3 and 100% of the scars incurred by these same edges may have hertzian initiations, depending upon the shape and size of the edge used, as well as other use-related variables. The large degree of variability in the proportions of scar initiation types observed in these experiments within the single activity of scraping, suggests that initiation type frequencies may exhibit even greater variability between use-actions.
Sawing

A total of 217 scars were created from sawing activities. A total of 100 bending initiations occurred while a further 113 had hertzian initiations and 4 scars were created by flakes that initiated with a snap. Again it is clear that use alone is not responsible for the observed variations in scar type frequencies removed in sawing activities. The frequency of bending initiations on edges used in sawing experiments is likewise subject to a number of interactions between both morphological and use variables, including:

1. Plan and longitudinal profile (p<0.001)
2. Plan and edge-angle (p=0.023)
3. Plan and contact material (p=0.028)

Plan and Longitudinal Profile (p<0.001)

The effect of the interaction between plan and longitudinal profile (see Figure 23) predicts that concave plans will produce greater proportions of bending scars when combined with convex or straight profiles. By comparison, greater proportions of bending scars are predicted to result from convex plans when combined with concave profiles; while straight plans are predicted to sustain greater frequencies of bending scars when combined with straight and concave profiles.

![Figure 23. Effect of interaction between Plan and Profile on predicted bending initiation frequencies when sawing (Level of other terms: Edge-angle – Low, Contact Material - Hard).](image-url)
Within these interactions, the ranges of predicted proportions of bending scars depending upon other relevant variables, are:

- Concave/Concave: 0-20%
- Concave/Convex: 3-83%
- Concave/Straight: 5-81%
- Convex/Concave: 50-88%
- Convex/Convex: 13-67%
- Convex/Straight: 11-61%
- Straight/Concave: 0-100%
- Straight/Convex: 0-31%
- Straight/Straight: 0-100%

Edge plan is a notable absence from the variables observed to affect frequencies of scar initiation types in scraping, given its relevance to those produced in sawing activities. The capacity for variables to affect the development of scar features differently with each use-action implies that analysts must know what action the tool was used in order to determine which variables are relevant to observed frequencies of initiation type. Far from indicating use-action from wear, these results indicate that the accurate interpretation of use-wear will be dependent upon knowing the use-action the tool was involved in from the outset.

**Plan and Edge-Angle (p=0.023)**

The combined effect of plan and edge-angle in determining frequencies of bending initiations is such that concave plans sustain low proportions of bending scars, regardless of edge-angle (see Figure 24). Convex and straight plans, however, are predicted to produce greater proportions of bending initiated scars with low edge-angles than with high; and the effect of edge-angle is more pronounced with straight plans than with convex plans.

![Figure 24. Effect of interaction between Plan and Edge-angle on predicted bending initiation frequencies when sawing (Level of other terms: Profile - Concave, Contact Material - Hard).](image-url)
The ranges of predicted proportions of bending scars for the interaction between plan and edge-angle and incorporating the effects of other relevant variables are as follows:

- **Concave/High**: 1-27%
- **Convex/High**: 11-50%
- **Straight/High**: 0%
- **Concave/Low**: 3-83%
- **Convex/Low**: 44-88%
- **Straight/Low**: 0-100%

**Plan and Contact Material (p=0.028)**

The proportion of bending scars likely to result from using each edge plan is different depending upon the contact material it is used to work. Convex and straight plans are predicted to consistently sustain higher proportions of bending scars than concave plans (see Figure 25).

However, concave and straight plans both have a likelihood of producing higher proportions of bending scars on soft wood than on hard, while the opposite is true of convex plans. The ranges of predicted proportions of bending scars likely to be incurred by plan and contact material combinations and incorporating the effects of other relevant variables are as follows:

- **Concave/Hard**: 0-50%
- **Convex/Hard**: 17-88%
- **Straight/Hard**: 0-88%
- **Concave/Soft**: 1-83%
- **Convex/Soft**: 11-72%
- **Straight/Soft**: 0-100%

![Figure 25. Effect of interaction between Plan and Contact Material on predicted bending initiation frequencies when sawing (Level of other terms: Edge-angle - Low, Profile - Concave).](image)
Inferences of Use from Scar Initiations

As with scar orientation, the nature and number of initiations incurred by an individual edge is subject to multiple interactions between both morphological and use variables. The degree to which initiation type may be regarded a reliable predictor of use will therefore be reliant upon knowledge of the effects of each of these factors. It is important to note here that the combinations of features that have a significant effect on initiation type developed through scraping activities are quite different to those found to affect initiation frequencies through sawing activities. This presents serious difficulties for wear analysts. Not only must they understand the effects of interactions between relevant variables on scar initiation type frequencies, but in order to determine which variables are relevant in each case, knowledge of the action responsible for the wear is required first. Furthermore, the ranges of proportions of bending initiated scars resulting from each activity substantially overlap with one another, making differentiation between activities and uses extremely difficult and complex. Similar complexities exist in the inference of use-actions and contact materials from patterns of fracture termination on scars.

SCAR TERMINATION

Scar terminations are argued to indicate both the relative hardness of the material worked and the action involved (e.g. Tringham et al. 1974; Odell and Odell-Vereecken 1980; Lewenstein 1981; Olausson 1983; Siegel 1984; Allen 1985; Salls 1985; Akoshima 1987; Ramos Milan 1990; Grimaldi and Lemorini 1992) in the generation of use-scarring. Step terminations are argued to occur more commonly in longitudinal actions than in transverse ones due to the nature of force applied in these actions (e.g. Tringham et al. 1974; Odell 1980, 1981, 1985a, 1985b; Kamminga 1982). Step and hinge terminations are also argued to only be produced on hard materials such as bone and wood (e.g. Tringham et al. 1974; Odell 1980, 1981, 1985a, 1985b; Kamminga 1982; Tomenchuck 1988a, 1988b, 1997).

Scraping

The types of terminations produced on scars created on edges used in scraping actions are, again, affected by multiple interactions. In this case significant interactions are present between all five of the morphological and use variables tested. Feather terminations dominate the termination types in all cases. However, significant interactions affecting the proportions of feather terminations generated through use are:
1. Plan and contact material (p<0.001)

2. Relief-angle and contact material (p<0.001)

3. Plan and edge-angle (p=0.002)

4. Edge-angle and relief-angle (p=0.021)

5. Plan and longitudinal profile (p=0.038)

**Plan and Contact Material (p<0.001)**

Figure 26 reveals the different effects of each plan with contact material on the predicted proportion of feather terminations incurred by edges used in scraping. Feather terminations are predicted to always be more common on soft wood than on hard. Scar terminations show greatest variation on convex plans relative to contact material; concave shaped edge plans show the least variation in termination types in response to alterations in contact material.

The ranges in predicted proportions of feather terminations incurred by the edge are again determined by the values of the other relevant variables which, in the case of terminations, includes profile, edge-angle and relief-angle. The remainder of the predicted proportions of feather terminations are outlined below are represented by step and snap terminations:

- Concave/Hard: 23-96%
- Concave/Soft: 42-95%
- Convex/Hard: 27-79%
- Convex/Soft: 66-98%
- Straight/Hard: 10-89%
- Straight/Soft: 12-95%

![Graph showing predicted proportion of feather terminated scars](image-url)

**Figure 26. Effect of interaction between Plan and Contact Material on predicted feather termination frequencies when scraping** (Level of other terms: Profile – Convex, Relief-angle – High, Edge-angle – High).
These results show that while it is true that scraping soft wood results in higher frequencies of feather terminated scars than does scraping harder wood, proportions of feather terminated scars almost always outweigh the combined predicted proportions of step and snap terminated scars on edges used to work hard woods. Variation in scar termination type cannot be accounted for by material hardness and use-action alone, with edge plan and relief-angle below, also affecting termination type frequencies in relation to the contact material worked.

Relief-Angle and Contact Material (p<0.001)

The interaction between relief-angle and contact material illustrated in Figure 27 reveals a significantly higher frequency of feather terminations predicted on soft wood when relief-angle is high than when it is low. On hard wood, however, relief-angle is predicted to have no effect on the proportions of feather terminations incurred by the working edge. The ranges in predicted proportions of feather terminations produced by this interaction and incorporating the effects of other relevant variables are:

- High/Soft: 33-99%
- Low/Soft: 12-93%
- High/Hard: 10-89%
- Low/Hard: 30-96%

![Figure 27. Effect of interaction between Relief-angle and Contact Material on predicted feather termination frequencies when scraping](image)

It is important to note that despite the emphasis currently placed on contact material as a determinant of scar termination type, contact material has been shown here to have a statistically significant effect on termination only when involved in an interaction with other variables. Further, these interactions state that the effect of relief-angle differs with...
contact material and not that contact material is a determinant in its own right. These results reveal that current explanations of termination type have misunderstood the role of contact material and therefore in the ability of this scar feature to identify artefact function.

**Plan and Edge-Angle (p=0.002)**
The susceptibility of edge plan to scar removals with feather terminations differs according to the edge-angle used (see Figure 28). Concave and straight plans are predicted to sustain significantly greater proportions of feather terminated scars when combined with a high edge-angle than with a low edge-angle. Feather terminations are predicted to occur in similar proportions on convex plans, regardless of edge-angle, and are significantly lower than those sustained by concave/high combinations.

The ranges of predicted proportions of feather terminated scars occurring on plan and edge-angle combinations and incorporating the effects of other relevant variables are:

- Concave/High: 51-99%
- Concave/Low: 23-93%
- Convex/High: 30-98%
- Convex/Low: 27-94%
- Straight/High: 12-95%
- Straight/Low: 10-91%

The ability for edge plan and angle to have such a strong effect on scar termination type frequencies, combined with the observed effects of longitudinal profile and relief-angle, discussed in the following sections, reveal that morphological features of the working edge play a considerable, and previously unconsidered, role in determining the types of scar terminations produced through use.
**Edge-Angle and Relief-Angle** (p=0.021)

Edge-angle and relief-angle are also found to affect the proportions of scars with feather terminations removed by scraping activities. Where edge-angle is high, the predicted proportion of feather terminations produced does not differ with relief-angle (see Figure 29). Where edge-angle is low, however, substantially greater proportions of feather terminations are predicted to occur with a low relief-angle than with a high relief-angle.

![Graph showing the effect of edge-angle and relief-angle on predicted feather termination frequencies when scraping](https://via.placeholder.com/150)

Figure 29. **Effect of interaction between Edge-angle and Relief-angle on predicted feather termination frequencies when scraping** (Level of other terms: Plan – Concave, Profile – Concave, Contact Material - Hard).

The ranges of predicted proportions of feather terminations produced through the interaction between edge-angle and relief-angle and depending upon the values of other relevant variables are:

- High (edge-angle) / High: 31-99%
- Low (edge-angle) / High: 10-94%
- High (edge-angle) / Low: 12-96%
- Low (edge-angle) / Low: 15-91%

**Plan and Longitudinal Profile** (p=0.038)

The effect of plan on proportions of feather terminated scars produced by scraping differs with longitudinal profile. As shown in Figure 30, significantly greater proportions of feather terminated scars are predicted to be removed from convex profiles than from either concave or straight profiles, regardless of which edge plan they are combined with. It is predicted that straight and concave profiles will have no effect on concave plans but use of straight profiles will result in significantly larger proportions of feather terminations when combined with either a convex or straight plan.
Ranges of predicted proportions of feather terminations for plan and profile combinations, and incorporating the effects of other relevant variables are as follows:

- Concave/Concave: 0-20%
- Concave/Convex: 3-83%
- Concave/Straight: 5-81%
- Convex/Concave: 50-88%
- Convex/Convex: 13-67%
- Convex/Straight: 11-61%
- Straight/Concave: 0-100%
- Straight/Convex: 0-31%
- Straight/Straight: 0-100%

These results highlight the existence of complex interrelationships between multiple variables affecting the types of terminations produced on scars from scraping activities. Differentiation of artefact use on the basis of scar termination alone has been shown here to be difficult in light of the ability for alternative variables to contribute to scar patterning and the capacity for both hard and soft woods to produce similar proportions of termination types.

**Sawing**

As with scraping activities, the types and frequencies of scar terminations produced by sawing activities are the product of multiple interactions between both use and morphological variables. Those identified in the experimental program carried out here and listed in order of their probability values, are:

1. Plan and longitudinal profile (p<0.001)
2. Plan and contact material (p<0.001)
3. Longitudinal plan and edge-angle (p=0.001)
4. Plan and edge-angle (p=0.016).

**Plan and Longitudinal Profile (p<0.001)**

The effect of plan on the types of scar terminations produced through sawing differs with longitudinal profile and is represented graphically in Figure 31. Frequencies of feather terminations are predicted to differ little with concave plans. However, significantly fewer frequencies of feather terminations are predicted on convex plans when combined with a concave profile than with convex or straight profiles. Feather termination frequencies are predicted to be greater on straight plans when combined with a straight profile than they are with either a concave or convex profile.

Once again, subject to the values of other relevant variables such as edge-angle and contact material, the ranges of predicted proportions of feather terminated scars resulting from plan/profile combinations are:

- Concave/Concave: 82-95%
- Concave/Convex: 67-100%
- Concave/Straight: 70-100%
- Convex/Concave: 0-60%
- Convex/Convex: 62-88%
- Convex/Straight: 41-100%
- Straight/Concave: 0-100%
- Straight/Convex: 0-100%
- Straight/Straight: 0-100%

![Figure 31. Effect of interaction between Plan and Longitudinal Profile on predicted feather termination frequencies when sawing (Level of other terms: Edge-angle – High, Contact Material - Hard).](image)

The morphology of the working edge therefore appears equally important to the production of various scar terminations in sawing activities, as has been identified above in scraping activities.
Plan and Contact Material (p<0.001)

The effect of plan on contact material is detailed in Figure 32 and shows that feather terminations are predicted to occur in significantly higher proportions on hard wood than on soft work when using a convex edge plan. By comparison, greater proportions of feather terminations are predicted to result on straight plans when used to work soft wood rather than hard wood. However, similar proportions of feather terminations are predicted when concave plans are used to work either soft or hard woods.

![Figure 32. Effect of interaction between Plan and Contact Material on predicted proportions of feather terminations when sawing (Level of other terms: Plan - Concave, Edge-angle - High).](image)

Ranges in the predicted proportions of scars incurring feather terminations with the interaction between plan and contact material and subject to the values of other relevant variables are as follows:

- Concave/Hard: 84-100%
- Convex/Hard: 32-100%
- Straight/Hard: 0-100%
- Concave/Soft: 67-100%
- Convex/Soft: 0-100%
- Straight/Soft: 80-100%

The ability for up to 100% of the scar terminations incurred by concave, convex and straight plans in sawing activities and on hard wood to be feathers, contradicts arguments that step terminations are indicative of both hard contact materials and longitudinal motions.
Longitudinal Profile and Edge-Angle (p=0.001)

The effect of profile on the proportion of scars with feather terminations removed from an edge in sawing activities is shown, in Figure 33, to differ according to angle of the edge used. Proportions of feather terminations are predicted to be higher when convex profiles are combined with low edge-angles rather than high. Straight profiles, however, are predicted to sustain higher proportions of feather terminations when combined with a high edge-angle. Concave plans are predicted to exhibit similar proportions of feather terminations regardless of edge-angle size.

![Graph showing predicted proportions of feather terminations](image)

Figure 33. Effect of interaction between Longitudinal Profile and Edge-angle on predicted proportions of feather terminations when sawing (Level of other terms: Plan - Concave, Contact Material - Hard).

The interaction between profile and edge-angle interactions and including the effects of additional relevant variables results in the following ranges in proportions of feather terminations:

- Concave/High: 0-100%
- Concave/Low: 11-94%
- Convex/High: 0-100%
- Convex/Low: 62-100%
- Straight/High: 80-100%
- Straight/Low: 41-100%

Plan and Edge-angle (p=0.016)

The final interaction affecting proportions of flake terminations on scars produced during sawing activities is between plan and edge-angle (see Figure 34). Greater proportions of feather terminations are predicted to occur on convex plans when combined with a high edge-angle, while frequencies of feather terminations are proportionately higher when removed from straight edge plans combined with a low edge-angle. Again similar
proportions of feather terminations are predicted for concave plans regardless of edge-angle, with concave plans always sustaining higher proportions of feather terminations than either of the other plans regardless of the edge-angle used.

The ranges of predicted proportions occurring within this interaction between plan and edge-angle and including the effects of other relevant variables are as follows:

- Concave/High: 67-100%
- Concave/Low: 70-700%
- Convex/High: 0-100%
- Convex/Low: 11-96%
- Straight/High: 0-100%
- Straight/Low: 41-100%

![Figure 34. Effect of interaction between Plan and Edge-angle on predicted proportions of feather terminations when sawing](image-url)

**Inferences of Use from Scar Terminations**

The existence of interactions between both use and morphological variables and the large degree of overlap in termination types detected for each action indicates that previous explanations of causes of scar terminations have underestimated the full array of processes involved. The results presented here demonstrate due to the complex interactions between variables contributing to the types of scar terminations produced through use, scar termination types are unable to perform as unique identifiers of artefact function.

**SCAR SIZE**

Scar size is currently used to support two aspects of stone artefact function in the wear-literate. The first is that scars generated through use are generally argued to be smaller than those produced intentionally through retouch, with scars measuring approximately
3mm or less regarded as the product of use (Tringham et al. 1974; Odell 1980; Newcomer 1985, 1986). A second argument is that scar size is correlated with contact material. Scars have therefore been argued to be larger and to occur more rapidly when working harder materials (e.g. Tringham et al. 1974; Odell 1980; Tomenchuck 1988a, 1988b, 1997). However, along with those of initiation, orientation and termination, scar size is shown here to be the product of a more intricate interplay between variables.

**Scraping**

Of each of the scar features discussed in this chapter, it is size that is affected by the greatest number of interactions between variables, in both scraping and sawing activities. While scars measuring 2mm or less represent the greatest proportion of all scars removed by experimentation, the relative proportions of sizes incurred during scraping activities differ according to the following interactions between use and morphological variables:

1. Relief-angle and contact material (p<0.001)
2. Plan and contact material (p=0.002)
3. Plan and longitudinal profile (p=0.004)
4. Longitudinal profile and contact material (p=0.005)
5. Edge-angle and relief-angle (p=0.014)
6. Plan and relief-angle (p=0.025).

**Relief-angle and Contact Material (p<0.001)**

The interaction between relief-angle and contact material outlined in Figure 35 predicts a greater proportion of very small scars when the tool is used on harder wood and combined with a low relief-angle and a smaller proportion of small scars when the tool is held at a high relief-angle. Differences between scar sizes are predicted to be less dramatic on edges used at a low relief-angle on softer wood, with small and medium sized scars becoming more common. High relief-angles are predicted to result in significantly higher proportions of large scars when working softer wood than when working harder wood. The range of proportions of scar sizes is again are predicted to differ in response to other interacting variables. The ranges in the predicted proportions of scars sizes for the interaction between relief-angle and contact material and depending upon the levels of other variables are:
Scarring and Use Wear - Experimental Results

<table>
<thead>
<tr>
<th>Relief Angle/Contact Material Combination</th>
<th>VS</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>VL</th>
</tr>
</thead>
<tbody>
<tr>
<td>High/Hard:</td>
<td>2-54%</td>
<td>10-64%</td>
<td>2-29%</td>
<td>2-76%</td>
<td>5-25%</td>
</tr>
<tr>
<td>Low/Hard:</td>
<td>13-92%</td>
<td>4-58%</td>
<td>1-25%</td>
<td>0-54%</td>
<td>0-3%</td>
</tr>
<tr>
<td>High/Soft:</td>
<td>15-60%</td>
<td>5-57%</td>
<td>5-54%</td>
<td>1-16%</td>
<td>0-39%</td>
</tr>
<tr>
<td>Low/Soft:</td>
<td>5-83%</td>
<td>6-58%</td>
<td>2-42%</td>
<td>0-46%</td>
<td>0-17%</td>
</tr>
</tbody>
</table>

Figure 35. Effect of interaction between Relief-angle and Contact Material on predicted proportions of scar sizes when scraping (Level of other terms: Plan - Concave, Profile - Concave, Edge-angle - High).

Plan and Contact material (p=0.002)

The interaction between plan and contact material is illustrated in Figure 36 and shows that the predicted proportions of very small and medium scars are greater on softer wood than on harder wood for all plan shapes and proportions of large scars greater on harder wood.

Figure 36. Effect of interaction between Plan and Contact Material on predicted proportions of scar sizes when scraping (Level of other terms: Profile - Concave, Edge-angle - High, Relief-angle - High).
than on softer wood for all plan shapes. Convex plans are predicted to result in higher proportions of very large scars on softer wood than on harder wood, with small scars dominating the sizes incurred on harder wood.

The ranges of predicted proportions of scar sizes for the interaction between plan and contact material in scraping, incorporating the effects of other important variables are:

<table>
<thead>
<tr>
<th>Plan/Contact</th>
<th>VS</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>VL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave/Hard</td>
<td>20-83%</td>
<td>4-31%</td>
<td>6-29%</td>
<td>1-54%</td>
<td>0-8%</td>
</tr>
<tr>
<td>Convex/Hard</td>
<td>4-80%</td>
<td>14-78%</td>
<td>4-28%</td>
<td>1-32%</td>
<td>0-25%</td>
</tr>
<tr>
<td>Straight/Hard</td>
<td>2-92%</td>
<td>5-69%</td>
<td>1-25%</td>
<td>1-76%</td>
<td>0%</td>
</tr>
<tr>
<td>Concave/Soft</td>
<td>5-84%</td>
<td>4-58%</td>
<td>4-28%</td>
<td>0-46%</td>
<td>0%</td>
</tr>
<tr>
<td>Convex/Soft</td>
<td>5-81%</td>
<td>2-22%</td>
<td>3-54%</td>
<td>1-22%</td>
<td>0-39%</td>
</tr>
<tr>
<td>Straight/Soft</td>
<td>8-73%</td>
<td>7-44%</td>
<td>2-46%</td>
<td>1-20%</td>
<td>0%</td>
</tr>
</tbody>
</table>

While large and very large sized scars represent smaller proportions of the total number of scars removed in scraping activities, it is possible that up to 76% of the scars produced on a single edge may be large sized, with fluctuations in frequency occurring in relation to the morphological properties of the edge being used. Concave profiles exemplify this, being found to produce similar proportions of large sized scars on both soft and hard woods. The ability for concave profiles to produce similar proportions of large sized scars regardless of the type of wood involved provides simple evidence of the inability of contact material to consistently explain variations in scar sizes produced through scraping activities.

**Plan and Longitudinal Profile (p=0.004)**

Scar sizes also differ with edge plan relative to the longitudinal profile used. Figure 37 illustrates this interaction and shows that significantly greater proportions of small scars are predicted to be removed on convex plans when combined with either a convex or concave profile, than with a straight profile. Straight plans are predicted to sustain greater proportions of large sized scars when combined with a concave profile than does any other plan/profile combination. High proportions of very small scars are predicted to be removed from concave plans regardless of which profile they are combined with and are substantially higher than any other combinations, with the exception of straight plan and straight profile morphologies.
The ranges of proportions of various scar sizes likely to occur on any of these plan/profile combinations is influenced by the effects of different edge characteristics and are as follows:

<table>
<thead>
<tr>
<th>Plan/Profile Combination</th>
<th>VS</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave/Concave</td>
<td>18-81%</td>
<td>4-28%</td>
<td>6-28%</td>
<td>1-52%</td>
<td>0%</td>
</tr>
<tr>
<td>Convex/Concave</td>
<td>6-59%</td>
<td>6-64%</td>
<td>7-54%</td>
<td>1-32%</td>
<td>0-15%</td>
</tr>
<tr>
<td>Straight/Concave</td>
<td>3-50%</td>
<td>14-44%</td>
<td>2-46%</td>
<td>4-76%</td>
<td>0%</td>
</tr>
<tr>
<td>Concave/Convex</td>
<td>44-84%</td>
<td>4-31%</td>
<td>5-25%</td>
<td>1-18%</td>
<td>0-8%</td>
</tr>
<tr>
<td>Convex/Convex</td>
<td>4-81%</td>
<td>5-78%</td>
<td>10-47%</td>
<td>1-13%</td>
<td>0%</td>
</tr>
<tr>
<td>Straight/Convex</td>
<td>6-67%</td>
<td>7-69%</td>
<td>7-46%</td>
<td>1-38%</td>
<td>0%</td>
</tr>
<tr>
<td>Concave/Straight</td>
<td>5-70%</td>
<td>6-58%</td>
<td>4-29%</td>
<td>1-54%</td>
<td>0%</td>
</tr>
<tr>
<td>Convex/Straight</td>
<td>16-80%</td>
<td>7-41%</td>
<td>3-23%</td>
<td>1-19%</td>
<td>0-39%</td>
</tr>
<tr>
<td>Straight/Straight</td>
<td>39-92%</td>
<td>5-45%</td>
<td>1-10%</td>
<td>1-24%</td>
<td>0-5%</td>
</tr>
</tbody>
</table>

**Longitudinal Profile and Contact Material** *(p=0.005)*

The effect of profile on the proportions of different sized scars resulting from use also differs with contact material. As illustrated in Figure 38, large and very large scar sizes are predicted to occur in greater proportions on edges used to work harder wood than they do on softer wood, with very small and small sized scars more common on the softer wood. These differences are most pronounced on convex profiles and straight profiles, with only
very subtle differences predicted to exist between proportions of different scar sizes on concave edge profiles.

The ranges of proportions of different scar sizes occurring on edges involving each of these combinations of profile and contact material and incorporating the effects of different levels of other relevant variables are:

<table>
<thead>
<tr>
<th>Profile/Contact Material</th>
<th>VS</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>VL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave/Hard:</td>
<td>2-81%</td>
<td>4-64%</td>
<td>2-19%</td>
<td>1-76%</td>
<td>0-5%</td>
</tr>
<tr>
<td>Convex/Hard:</td>
<td>4-83%</td>
<td>7-78%</td>
<td>7-28%</td>
<td>1-38%</td>
<td>0-8%</td>
</tr>
<tr>
<td>Straight/Hard:</td>
<td>16-92%</td>
<td>5-45%</td>
<td>4-29%</td>
<td>0-54%</td>
<td>0-25%</td>
</tr>
<tr>
<td>Concave/Soft:</td>
<td>8-60%</td>
<td>6-44%</td>
<td>10-54%</td>
<td>1-34%</td>
<td>0-15%</td>
</tr>
<tr>
<td>Convex/Soft:</td>
<td>16-84%</td>
<td>2-19%</td>
<td>5-47%</td>
<td>1-15%</td>
<td>0%</td>
</tr>
<tr>
<td>Straight/Soft:</td>
<td>25-78%</td>
<td>10-58%</td>
<td>2-19%</td>
<td>1-46%</td>
<td>0-39%</td>
</tr>
</tbody>
</table>

Figure 38. Effect of interaction between Profile and Contact Material on proportions of scar sizes when scraping (Level of other terms: Longitudinal Profile – Concave, Edge-angle – High, Relief-angle – High).

Both use and morphological variables must be considered with interpreting the causes of scar sizes and frequencies on edges used in scraping activities.

**Edge-Angle and Relief-Angle** \((p=0.014)\)

Proportions of very small scars are predicted to be greater on low edge-angles when working proceeds using a high relief-angle (see Figure 39). By comparison, the proportions of large scars are predicted to be much greater if both edge-angle and relief-angle are low.
Proportions of medium and large scars, however, are greater on high edge-angles when worked at a low rather than a high relief-angle.

The ranges of proportions of different sized scars occurring from the interaction between edge-angle and relief-angle and incorporating the effects of different levels of other relevant variables are as follows:

<table>
<thead>
<tr>
<th>Edge Angle/Relief Angle Combination</th>
<th>VS</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>VL</th>
</tr>
</thead>
<tbody>
<tr>
<td>High/High</td>
<td>3-84%</td>
<td>5-78%</td>
<td>2-35%</td>
<td>1-50%</td>
<td>0-39%</td>
</tr>
<tr>
<td>High/Low</td>
<td>25-92%</td>
<td>4-58%</td>
<td>1-21%</td>
<td>1-11%</td>
<td>0%</td>
</tr>
<tr>
<td>Low/High</td>
<td>2-82%</td>
<td>2-54%</td>
<td>3-54%</td>
<td>1-38%</td>
<td>0-8%</td>
</tr>
<tr>
<td>Low/Low</td>
<td>13-72%</td>
<td>4-58%</td>
<td>8-42%</td>
<td>2-54%</td>
<td>0-17%</td>
</tr>
</tbody>
</table>

The presence of interactions involving relief-angle and their effect on scar sizes in scraping activities suggests that only very subtle differences within a single action may be required to affect the proportions of various scar sizes observed on used edges of stone artefacts. It is therefore not only differences between use-actions, but also within them that contribute to variability in the development of scar features.

**Plan and Relief-Angle** *(p=0.025)*

The final interaction affecting scar size on edges used in scraping activities is between plan and relief-angle (see Figure 40). Higher proportions of very small scars are predicted to occur when concave plans are used at a low relief-angle than when used at a high relief-
angle. Concave plans used at a high relief-angle are predicted to result in slightly greater proportions of small, medium and large scars.

![Graph showing effect of interaction between Plan and Relief-angle on proportions of scar sizes when scraping](image)

Figure 40. Effect of interaction between Plan and Relief-angle on proportions of scar sizes when scraping (Level of other terms: Longitudinal Profile – Concave, Edge angle – High, Contact Material - Hard).

Higher proportions of very small scars are also predicted to result on convex and straight plans when worked using a low relief-angle, with straight plans sustaining higher proportions of large sized scars than any other combination when worked with a high relief-angle. The greatest range in scar sizes is predicted for convex/high plan/relief-angle combinations.

The ranges of proportions of different scar sizes existing from the interaction between plan and relief-angle, and including the effects of different levels of other relevant variables are as follows:

<table>
<thead>
<tr>
<th>Plan/Relief Angle Combination</th>
<th>Very Small (%)</th>
<th>Small (%)</th>
<th>Medium (%)</th>
<th>Large (%)</th>
<th>Very Large (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave/High</td>
<td>32-84%</td>
<td>4-57%</td>
<td>7-29%</td>
<td>1-23%</td>
<td>0%</td>
</tr>
<tr>
<td>Convex/High</td>
<td>4-55%</td>
<td>2-78%</td>
<td>8-54%</td>
<td>4-32%</td>
<td>0-39%</td>
</tr>
<tr>
<td>Straight/High</td>
<td>2-65%</td>
<td>17-69%</td>
<td>2-46%</td>
<td>1-76%</td>
<td>0%</td>
</tr>
<tr>
<td>Concave/Low</td>
<td>5-83%</td>
<td>4-58%</td>
<td>4-23%</td>
<td>1-54%</td>
<td>0%</td>
</tr>
<tr>
<td>Convex/Low</td>
<td>16-81%</td>
<td>6-58%</td>
<td>3-30%</td>
<td>1-22%</td>
<td>0%</td>
</tr>
<tr>
<td>Straight/Low</td>
<td>8-92%</td>
<td>2-42%</td>
<td>1-42%</td>
<td>1-45%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Every variable tested in the experimental program has been found to affect the frequencies of different scar sizes produced through scraping activities. These results again highlight the complexities and subtleties of using scar features as distinctive indicators of function. The presence of contact material as a significant variable only when included in an
interaction with other variables, such as plan and profile, indicates that within the confines of this experimental program, contact material alone was never the sole cause of variation in scar patterning. As such, it is difficult to simply state how much of any pattern in scar size reflects contact material hardness. Similar levels of complexity exist for the different proportions of scar sizes produced through sawing activities.

**Sawing**

Statistical analyses of the effect of use and morphological variables upon the proportions of different scar sizes produced on edges used in sawing activities identified the following interactions between variables to be statistically significant; listed in order of probability:

1. Plan and longitudinal profile \((p<0.001)\)
2. Longitudinal profile and contact material \((p<0.001)\)
3. Plan and edge-angle \((p=0.002)\)
4. Plan and contact material \((p=0.005)\)
5. Edge-angle and contact material \((p=0.006)\)

As with scraping, all of the variables tested, including plan, profile, edge-angle and contact material was found to affect the proportions of scar sizes produced through sawing activities.

**Plan and Longitudinal Profile \((p<0.001)\)**

In sawing activities, the effect of plan on the proportion of different sized scars which result on the working edge is again found to differ in combination with longitudinal profile. Figure 41 outlines the effects of this interaction on scar sizes and shows a greater proportion of small scars are predicted to result from using concave profiles while straight profiles tend to sustain greater proportions of very small scars. Highest proportions of small scars are predicted to occur on straight plans when combined with concave profiles, followed by convex and, finally, straight profiles. Equal numbers of very small scars are predicted to occur on straight profiles when combined with either concave or straight plans, while less result when combined with convex plans. Large scars are predicted to occur in greatest proportions on convex plans and are highest when convex/convex plan/profile combinations are used. Convex profiles result in very different proportions of sizes with each plan, with medium scars dominant when combined with concave plans,
large scars dominant when combined with convex plans and small scars dominate when combined with straight plans. Convex profiles are predicted to generally experience low proportions of very small scars, regardless of plan combinations.

![Figure 41. Effect of interaction between Plan and Longitudinal Profile on proportions of scar sizes when sawing (Level of other terms: Edge-angle – High, Contact Material - Hard).](image)

In each case however, the ranges of predicted proportions of sizes produced through use differ with the levels of other relevant and interacting variables. The ranges of proportions of scar sizes occurring in this experimental program were as follows:

<table>
<thead>
<tr>
<th>Plan/Profile Combination</th>
<th>VS</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>VL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave/Concave:</td>
<td>0-51%</td>
<td>29-73%</td>
<td>0-45%</td>
<td>0-38%</td>
<td>0-7%</td>
</tr>
<tr>
<td>Convex/Concave:</td>
<td>0-52%</td>
<td>0-46%</td>
<td>0-39%</td>
<td>0-100%</td>
<td>0%</td>
</tr>
<tr>
<td>Straight/Concave:</td>
<td>0-85%</td>
<td>3-99%</td>
<td>0-20%</td>
<td>0-11%</td>
<td>0%</td>
</tr>
<tr>
<td>Concave/Convex:</td>
<td>0-23%</td>
<td>5-55%</td>
<td>13-71%</td>
<td>0-15%</td>
<td>0%</td>
</tr>
<tr>
<td>Convex/Convex:</td>
<td>0-17%</td>
<td>1-42%</td>
<td>27-47%</td>
<td>8-63%</td>
<td>0%</td>
</tr>
<tr>
<td>Straight/Convex:</td>
<td>8-68%</td>
<td>7-81%</td>
<td>5-25%</td>
<td>0-3%</td>
<td>0%</td>
</tr>
<tr>
<td>Concave/Straight:</td>
<td>1-48%</td>
<td>1-52%</td>
<td>5-55%</td>
<td>0-13%</td>
<td>0-6%</td>
</tr>
<tr>
<td>Convex/Straight:</td>
<td>0-40%</td>
<td>1-37%</td>
<td>13-62%</td>
<td>6-30%</td>
<td>0-23%</td>
</tr>
<tr>
<td>Straight/Straight:</td>
<td>47-84%</td>
<td>7-32%</td>
<td>0-26%</td>
<td>0-4%</td>
<td>0%</td>
</tr>
</tbody>
</table>

The morphology of used edges is therefore found to be an important determinant of the sizes of scars developed through use, irrespective of the use-action or contact material involved in their removal. In failing to take these sources of difference into consideration, wear analysts have overlooked what is increasingly being shown to be an essential source of variation in all types of scar features.
Longitudinal Profile and Contact Material (p<0.001)

The interaction between longitudinal profile and contact material on the proportions of different sized scars produced through use predicts that, at a general level, large scars will occur in greater proportions on softer wood and medium scars while proportions of medium sized scars will be higher on harder wood (Figure 42). Convex profiles are predicted to result in greater proportions of small and medium sized scars on harder wood with very small scars more common on softer wood. By comparison, convex and straight profiles are predicted to sustain greater proportions of medium sized scars on harder wood and smaller sized scars on softer wood.

![Figure 42. Effect of interaction between Longitudinal Profile and Contact Material on predicted proportions of scar sizes when sawing (Level of other terms: Plan - Concave, Edge-angle - High).](image)

The ranges in proportions of each of these scar sizes with profile and contact material combinations and including the effects of different levels of other important variables are as follows:

<table>
<thead>
<tr>
<th>Profile/Contact Material</th>
<th>VS</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>VL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave/Hard:</td>
<td>0%</td>
<td>0.99%</td>
<td>0.39%</td>
<td>0.100%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Convex/Hard:</td>
<td>42-3%</td>
<td>1.81%</td>
<td>10.71%</td>
<td>0.63%</td>
<td>0%</td>
</tr>
<tr>
<td>Straight/Hard:</td>
<td>15.48%</td>
<td>4.32%</td>
<td>19.62%</td>
<td>0.9%</td>
<td>0%</td>
</tr>
<tr>
<td>Concave/Soft:</td>
<td>1.85%</td>
<td>3.48%</td>
<td>0.45%</td>
<td>0.58%</td>
<td>0%</td>
</tr>
<tr>
<td>Convex/Soft:</td>
<td>1.68%</td>
<td>7.51%</td>
<td>1.55%</td>
<td>0.22%</td>
<td>0%</td>
</tr>
<tr>
<td>Straight/Soft:</td>
<td>1.84%</td>
<td>7.52%</td>
<td>1.31%</td>
<td>4.30%</td>
<td>0.23%</td>
</tr>
</tbody>
</table>
Plan and Edge-Angle (p=0.002)

The effect of edge-angle on the proportions of scar sizes produced by each edge plan in sawing activities is illustrated in Figure 43. This figure shows that all plans are predicted to result in higher proportions of large sized scars when combined with a low edge-angle than with a high edge-angle. However, the extent to which scar size increases with a low edge-angle is different for each plan. Substantially lower proportions of small scars are predicted to occur on concave plans when combined with a low edge-angle than with a high edge-angle, with proportions of large scars exceeding those of small scars on low edge-angles. Concave plans, combined with low edge-angles, also produce higher predicted proportions of very large scars than any other plan/edge-angle combination. Substantially higher numbers of large scars are produced on convex plans when combined with a low edge-angle, with predicted proportions of large scar numbers on low edge-angles more than treble those which occur on high edge-angles. Lower proportions of large sized scars are predicted on straight plans than any other combination of plan and angle and tend to occur on low edge-angles only.

![Figure 43. Effect of interaction between Plan and Edge-angle on predicted proportions of scar sizes when sawing (Level of other terms: Profile – Concave, Contact Material – Hard).](image)

The ranges of proportions of scar sizes occurring from plan and edge-angle combinations and including the effects of other levels of relevant variables are:

<table>
<thead>
<tr>
<th>Plan/Edge Angle Combination</th>
<th>VS</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>VL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave/High</td>
<td>0-51%</td>
<td>0-73%</td>
<td>0-71%</td>
<td>0-15%</td>
<td>0%</td>
</tr>
<tr>
<td>Convex/High</td>
<td>0-52%</td>
<td>1-46%</td>
<td>1-62%</td>
<td>0-63%</td>
<td>0%</td>
</tr>
<tr>
<td>Straight/High</td>
<td>0-85%</td>
<td>14-99%</td>
<td>0-19%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Concave/Low</td>
<td>0-23%</td>
<td>21-55%</td>
<td>24-55%</td>
<td>0-38%</td>
<td>0-7%</td>
</tr>
</tbody>
</table>
Scarring and Use-Wear - Experimental Results

Chapter 7

Convex/Low: 0-15% 0-39% 0-58% 6-100% 0-23%
Straight/Low: 0-76% 3-68% 12-26% 0-11% 0%

**Plan and Contact Material (p=0.005)**

The interaction between plan and contact material (see Figure 44) indicates that proportions of very small scars are predicted to be consistently greater on softer wood than on harder wood. Proportions of medium and large sized scars are predicted to be much greater on harder than on softer wood and are dominant on convex/hard combinations of plan and contact material. Highest proportions of very small and small sized scars are predicted to occur on straight profiles when used to work harder and softer woods respectively.

![Figure 44. Effect of interaction between Plan and Contact Material on predicted proportions of scar sizes when sawing (Level of other terms: Profile – Concave, Edge-angle – High).](image)

The ranges of proportions of scar sizes predicted within plan and contact material combinations and including the effects of other levels of relevant variables are:

<table>
<thead>
<tr>
<th>Plan/Contact Material</th>
<th>VS</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>VL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave/Hard</td>
<td>0-23%</td>
<td>1-99%</td>
<td>24-71%</td>
<td>0-38%</td>
<td>0-7%</td>
</tr>
<tr>
<td>Convex/Hard</td>
<td>0-28%</td>
<td>0-40%</td>
<td>0-62%</td>
<td>6-100%</td>
<td>0%</td>
</tr>
<tr>
<td>Straight/Hard</td>
<td>0-48%</td>
<td>26-99%</td>
<td>1-26%</td>
<td>0-11%</td>
<td>0%</td>
</tr>
<tr>
<td>Concave/Soft</td>
<td>1-51%</td>
<td>34-52%</td>
<td>1-55%</td>
<td>0-19%</td>
<td>0-6%</td>
</tr>
<tr>
<td>Convex/Soft</td>
<td>1-52%</td>
<td>16-46%</td>
<td>0-47%</td>
<td>0-58%</td>
<td>0-23%</td>
</tr>
<tr>
<td>Straight/Soft</td>
<td>64-85%</td>
<td>3-31%</td>
<td>0-25%</td>
<td>0-7%</td>
<td>0%</td>
</tr>
</tbody>
</table>

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As with scraping activities, the interactions between plan and contact material, and edge-angle and contact material (discussed below) indicate that contact material represents only one of many important variables affecting the sizes of scars produced through sawing activities. Contact material is therefore unable to be forwarded as a sole determinant of variation in the sizes of scars observed on the used edges of prehistoric stone artefacts.

**Edge-Angle and Contact Material (p=0.006)**

The interaction between edge-angle and contact material is the last significant interaction identified to affect the predicted proportions of scar sizes on edges used in sawing activities. The effect of this interaction is illustrated in Figure 45 and shows higher proportions of medium and large sized scars are predicted to occur on high edge-angles than on low edge-angles. Proportions of very small scars are predicted to be greatest on low edge-angles used to work softer wood, with proportions of very small scars tending to be much lower on edges used to work harder wood.

![Figure 45. Effect of interaction between Edge-angle and Contact Material on predicted proportions of scar sizes when sawing](image)

The ranges of proportions of scars sizes for this final interaction between edge-angle and contact material and including the effects of different levels in other important variables are as follows:

<table>
<thead>
<tr>
<th></th>
<th>VS</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>VL</th>
</tr>
</thead>
<tbody>
<tr>
<td>High/Hard</td>
<td>0-48%</td>
<td>4-99%</td>
<td>1-71%</td>
<td>0-63%</td>
<td>0%</td>
</tr>
<tr>
<td>High/Soft</td>
<td>17-85%</td>
<td>14-51%</td>
<td>0-31%</td>
<td>0-13%</td>
<td>0%</td>
</tr>
<tr>
<td>Low/Hard</td>
<td>0-47%</td>
<td>0-68%</td>
<td>0-58%</td>
<td>0-100%</td>
<td>0-7%</td>
</tr>
<tr>
<td>Low/Soft</td>
<td>1-76%</td>
<td>3-52%</td>
<td>11-55%</td>
<td>3-58%</td>
<td>0-23%</td>
</tr>
</tbody>
</table>
Inferences of Use from Scar Size

While interactions between plan and profile and other relevant variables have been identified for both sawing and scraping activities, the effects of these variables on scar size frequency within each interaction are quite different for each use-action. This means that while wear analysts will be able to assert that a statistically significant interaction exists between plan and profile on scar size regardless of which action was involved; they will be unable to determine how this interaction affects observed frequencies without knowing exactly which action produced it. As has been identified with other scar features, it is apparent that the interpretation of scar size through use-wear is dependent upon knowing the artefacts function from the outset.

The results of the previous discussion are summarized in Table 3 which compares the combined effects of morphological variables (plan, profile and edge-angle) with those of use variables (relief-angle and contact material) on the frequency of scar features produced through scraping and sawing activities.

Table 3. Effect of Usage and Morphology variables on determination of scar features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Action</th>
<th>Usage</th>
<th>Morphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td>Scraping</td>
<td>p&lt;0.001</td>
<td>p=0.009</td>
</tr>
<tr>
<td></td>
<td>Sawing</td>
<td>p=0.578</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Initiation</td>
<td>Scraping</td>
<td>p=0.332</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Sawing</td>
<td>0.703</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Termination</td>
<td>Scraping</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Sawing</td>
<td>p=0.042</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Size</td>
<td>Scraping</td>
<td>p=0.001</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Sawing</td>
<td>p=0.306</td>
<td>p&lt;0.001</td>
</tr>
</tbody>
</table>

Table 3 shows that while use related variables play an important role in the development of scar features, in all cases, except scar orientation when scraping, morphological variables are shown to be as significant or more significant determinants of scar features than use related variables.

These results indicate that individual scar features may be poor indicators of artefact use. However wear analysts argue that it is not the individual features of wear-scars but their combinations and frequencies that contribute to interpretations of function (e.g. Tringham
et al. 1974; Odell 1981; Kamminga 1982; Tomenchuk 1988a, 1997). As such, before conclusions regarding the capacity for scarring to indicate artefact function can be made, it is first necessary to explore the effects of use and morphological variables upon scar frequencies.

SCARRING FREQUENCY

In addition to use and morphology, it was considered possible that the length of time an edge was used could impact upon the number of scars visible to the analyst upon recovering an artefact. In order to evaluate which attributes of artefact morphology and its use were most involved in creating differences in scar frequency, a statistical analysis was conducted to answer the question is scar frequency the product of use, morphology or length of use (discussed from here on as longevity) or a combination of these aspects of artefact use? Poisson generalized linear models (GLM’s) were fitted, each having number of scars as the response variable and one of the three groups of variables as explanatory terms (Drennan 1996). The change in deviance for each, relative to a null model (in which no explanatory variables occur) and associated p-value are compared in Table 4. These data only relate to scraping activities.

Table 4. Effect of various aspects of artefact use on generation of edge-scarring in Scraping Activities

<table>
<thead>
<tr>
<th>Terms</th>
<th>Deviance</th>
<th>df</th>
<th>Change in df</th>
<th>Significance Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphology</td>
<td>272.66</td>
<td>58</td>
<td>160.55</td>
<td>0.004</td>
</tr>
<tr>
<td>Usage</td>
<td>420.93</td>
<td>68</td>
<td>12.28</td>
<td>0.580</td>
</tr>
<tr>
<td>Longevity</td>
<td>337.46</td>
<td>70</td>
<td>95.75</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

The table shows that in scraping, length of use (p<0.001) has the most effect on scar frequency but that artefact morphology (p=0.004), particularly edge plan, profile and angle also contribute significantly to variation in the abundance of scars formed. Other variables, such as contact material and relief-angle do not have a significant effect on scar frequency.

In sawing activities, the affect of each of these variables is different. Neither morphology nor usage variables are found to effect frequency of edge-scarring and length of use was found to be the only significant contributor (p=0.039).

While usage variables were not found to affect scar frequency on their own it was considered possible that interactions existed between usage and morphology variables that
contributed to scar frequency. As such, a second Poisson GLM was fitted to the data, in which plan, longitudinal profile, edge-angle, relief-angle, contact material and all two-way interactions were compared with cumulative scar number as the response variable.

For scraping activities, the analysis identified significant interactions between edge-angle and relief-angle ($p=0.024$) and plan and longitudinal profile ($p=0.045$), with each contributing to the frequency of edge-scarring. The interaction between edge-angle and relief-angle is graphed in Figure 46 below. This figure, and subsequent Figures 47 and 48, plot predicted scar frequencies relative to various morphological and use variables. Again, lines have been drawn connecting the same variables in these figures in order to clarify connections between relevant variables; they do not indicate that intermediate measures exist between markers.

![Figure 46. The interaction between edge-angle and relief-angle on predicted frequencies of edge-scarring in scraping actions (Level of other terms: Plan - Concave, Profile - Concave, Contact Material - Hard).](image)

Figure 46 indicates that, where relief-angle is high, there is no effect on edge-angle. However, where relief-angle is low, a low edge-angle will result in approximately three times the number of scars than those incurred by high edge-angles.

As was the case with scar features, scar frequencies will fall within a predicted range depending upon the effects of different levels of other significant interactions - in this case plan and profile. As such, the ranges in proportions of scar frequencies with edge-angle and relief-angle, including the effects of plan and profile are:

- **High/High**: 1.6-9.8
- **Low/High**: 4.9-12.1
- **High/Low**: 2.5-4.9
- **Low/Low**: 2.5-15.5
The interaction between edge plan and longitudinal profile, illustrated in Figure 47, shows that concave plans incur the greatest numbers of scars when combined with convex profiles, and that convex and straight plans sustain most scars when combined with straight profiles. Lowest scar frequencies occur when concave plans are combined with concave profiles, and convex and straight plans are combined with convex profiles.

The ranges of scar frequencies produced by this interaction and including the effects of edge-angle and relief-angle are:

- Concave/Concave: 4-6.1
- Concave/Convex: 4.4-13.9
- Concave/Straight: 3-9.7
- Convex/Concave: 0.8-13.5
- Convex/Convex: 2.5-8
- Convex/Straight: 4.9-15.5
- Straight/Concave: 0.8-2.5
- Straight/Convex: 2.5-8
- Straight/Straight: 3.8-12

In sawing activities, edge-angle \(p<0.001\) and contact material \(p=0.039\) were found to have an effect on scar frequency. The effect of each of these variables is illustrated in Figure 48. Low edge-angles are predicted to incur greater scar frequencies than high edge-angles, regardless of contact material, and softer wood consistently generated greater scar numbers than harder wood, regardless of edge-angle.

These results indicate that only a very small portion of scar frequency is the product of use alone, with edge morphology and duration of use playing much more significant roles in the frequencies of scars on used artefact edges. Furthermore, fewer interactions between variables have been found to affect scar frequency than scar features. This discovery indicates that not all of the variation noted in scar features can be explained by differential
scar frequency. These results may have implications for interpretations of scraping activities. The wide variability in scar features, produced through scraping, suggests that particular features alone, or in combination, may be insufficiently distinctive to allow interpretation of function. In addition, scar frequencies in scraping activities are found to be unaffected by contact material hardness and, within the confines of the experimental program conducted, neither scar features nor frequencies can be regarded as distinctive of scraping activities. In the case of sawing, the effects of edge-angle and contact material show clear differences in predicted scar frequencies. This suggests that, in some cases, it may be possible to differentiate between contact material hardness on the basis of scar frequency, taking edge-angle into account.

While the preceding discussions illustrate that variations in the frequencies of scar features are subject to a number of important interactions between variables, resulting in wide ranges of proportions of these features depending upon the different levels of relevant variables, in each case the results for scraping and sawing were discussed separately. In the following section, comparisons are made between the ranges of proportions of scar features for both scraping and sawing actions in order to determine whether these actions may be differentiated from one another, on the basis of scar features.

Comparing Scar Features between Actions

Central to the identification of artefact function through wear analyses is the idea that different artefact functions may be differentiated from one another on the basis of

Figure 48. Effects of Edge-angle and Contact Material on predicted frequencies of edge-scarring in sawing actions.
differential wear patterning. It is, therefore, necessary to compare the extent to which the ranges in proportions of scar features differ with each use-action.

The discovery in the previous sections that, within any one use-action, a wide range of variability exists in the proportions of resulting scar features and frequencies could be differentiated. However, direct comparisons of the frequencies of scars and proportions of scar features will not be diagnostic of different actions because of the number of complex interactions between variables noted to contribute to the development and frequencies of each scar feature.

Furthermore, for scar frequencies and features the variables and interactions identified as statistically significant differ with use-action. Where the same variables are involved in an interaction for both scraping and sawing actions, such as plan and profile, the effects of those interactions on the proportions of that feature, or frequencies of scars produced, are different. In order to understand the cause of scar patterning and frequency on a used edge and in order to determine which morphological and use features might be having an effect on feature development, it is necessary to know which action was initially involved in generating the wear. Given that this information is unknown to the archaeologist and is, itself, the goal of investigation, this should create concern about the ability of analysts to differentiate between actions using the available information. While the analyst is able to view the various morphological features of the edge being examined, the appropriate interpretation of each of those features may be entirely different depending upon the action involved in generating them. As such, while edge morphology is an important determinant of scar features, it may not be able to assist the analyst in determining function. As such, in order for the analyst to identify the effects of actions and contact materials on scar development and to successfully differentiate between them, contact material and action alone must provide sufficient indicators of use.

Figures 49 and 50 below plot the ranges of proportions of various scar features relative to each action and contact material involved in this experimental program. These are not confidence intervals. They show the predicted range in proportions, from the minimum to the maximum prediction, for each scar feature. Figure 49 shows the ranges of proportions of dorsal to ventral orientated scars, initiations produced by bending forces and feather terminated scars, produced by sawing and scraping, at both high and low relief-angles, and on both hard and soft wood. The ranges of predicted proportions outlined include the
variability produced by interactions with morphological variables, the effects of which would be unknown to an analyst.

Figure 49. Predicted ranges (i.e. minimum prediction to maximum prediction) of proportions of ventral to dorsal oriented scars, bending initiations and feather terminations, over all combinations of plan, profile, edge-angle and relief-angle, produced by sawing and scraping actions on both hard and soft wood.

Heavy overlaps are visible between the ranges in proportions of all three scar features, with differences in proportions of initiation type virtually non-existent. Likewise, ranges of proportions of feather terminations produced through scraping, at either low or high relief-angles, fall neatly within those predicted for sawing actions, making differences between them non-distinguishable. While greater differences are visible with proportions of dorsal to ventral scar orientations, they are not sufficient to suggest that different actions were involved in their production.

Ranges in proportions of scar sizes, produced through scraping and sawing actions are plotted in Figure 50, which shows similarly high levels of overlap between actions and contact materials. The extent to which overlaps exist between these features regardless of action and contact material, suggests that differentiation between scar features is insufficient to allow the identification of artefact function.

Comparisons between scar frequencies reveal similar problems for differentiating between artefact functions. Predicted ranges of scar frequencies for each action and contact material are as follows:
Scarring and Use-Wear - Experimental Results

Chapter 7

<table>
<thead>
<tr>
<th>Action</th>
<th>Hard</th>
<th>Soft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawing</td>
<td>2.6-6.6</td>
<td>4.4-11</td>
</tr>
<tr>
<td>Scraping/High Relief-angle</td>
<td>1.6-12.1</td>
<td>1.6-12.1</td>
</tr>
<tr>
<td>Scraping/Low Relief-angle</td>
<td>0.8-15.5</td>
<td>0.8-15.5</td>
</tr>
</tbody>
</table>

Figure 50. Predicted ranges (i.e. minimum prediction to maximum prediction) of proportions scar sizes, over all combinations of plan, profile, edge-angle and relief-angle, produced by sawing and scraping actions on both hard and soft wood.

The ranges of predicted scar frequencies incurred by an edge used to saw harder, or softer, wood fall well within those produced by edges used to scrape harder or softer woods at either a low or high relief-angle. As such, while scar frequencies produced from sawing harder wood are significantly different from those used to saw softer wood, they are not clearly distinguishable from those used to work either in scraping activities.

CONCLUSIONS

The experiments conducted in this study indicate that a wide range of variables contribute to the nature and number of scars produced on the working edges of stone artefacts through use in scraping and sawing activities. While it must be remembered that experimental programs, such as the one conducted in this thesis, cannot attempt to explain scar patterning produced through less controlled, every day hunter-gatherer tool use, these results have important implications for the future studies into the interpretation of artefact function through wear. These can be summarized into four main points.
Firstly, the importance of morphological variables upon the frequencies and features of the scars produced through use. Edge shape in plan, and in profile, as well as the size of the angle used is each found to have differing effects on scar features, either in isolation or as part of an interaction, and depending upon the action involved in their development. Fewer significant effects are found to exist between these same variables in determining the number of scars produced through each action. Any attempt at interpretation of artefact function, based on scar frequency and patterning, must therefore consider the effects of edge morphology on the patterning visible.

Secondly, the significance of morphological variables is greater than that of use-related variables, with use-related variables, in some cases, found to have no effect on scar development at all. As such, the current emphasis upon use-related variables as determinants of scar frequency and patterning needs to be reevaluated in light of this evidence.

Thirdly, the causes of scar features and frequencies are highly complex, resulting in a range of predicted proportions or frequencies for each significant effect identified. In addition, the predicted effects of each interaction differ for each action and, in many cases, the identification of statistically significant variables responsible for a given scar patterning necessarily requires knowledge of the function for which the edge was initially used. In the absence of this information, the predicted range of proportions of scars and scar features and areas of overlap between actions/contact materials are too great to allow their differentiation on the basis of scar patterning.

A final point is that one of the goals of controlled experimentation is to control the variation in contexts and the equal replication of all treatment combinations (i.e. combinations of variables). In so doing, controlled experiments remove much of the complexity that occurs in daily activities. The experimental program undertaken here tested the effects of only some of a great many variables that may contribute to scar patterning. It therefore seems likely that even broader ranges of variation, and thus greater complexity, could be expected from less controlled experiments and from the real life situations being interpreted by the wear analyst.

In the following chapter the effects of each of these variables upon artefact performance are explored.
CHAPTER 8

MORPHOLOGY AND FUNCTION – EXPERIMENTAL RESULTS

INTRODUCTION

Central to the research aims of this thesis is the identification of those morphological, or use related variables that contribute to an artefact's ability to perform and how these differ in conjunction with actions and contact materials. In this thesis, performance is discussed in relation to both an artefact's ability to achieve high levels of material loss (scraping) or cut depth (sawing) and to maintain those performance levels over time. It is assumed that rapid material loss/cut depth and the length of time an artefact is able to perform are two qualities likely to be considered desirable to stone artefact users. Artefacts that can perform a task quickly and effectively and maintain this ability with use are thought to reduce the number of artefacts required to complete a task. This, in turn, reduces the time and effort required in procuring raw materials and manufacturing more artefacts. By systematically controlling particular variables, and varying others, it is possible to determine which are integral to an artefact's ability to perform and which are peripheral to each action, whereby morphological variation may occur without affecting artefact performance.

The goal of this chapter is, therefore, to identify the effects of specific variables upon artefact performance over both short term and longer term usage in order to better understand the relationship between stone artefact morphology and function.

ARTEFACT LONGEVITY/USE-LIVES

The amount of use a knapper is able to gain from an individual artefact defines how long an artefact will remain in active use in its current state. Within the confines of this thesis, this period of active use of an artefact is referred to as its use-life and is defined by the number of 200 stroke runs the artefact is able to complete before minimum cut or weight removals are no longer attained and the artefact ceased to be used (see Chapter 6). In a prehistoric context, once an artefact ceased to reach minimal levels of performance, either the edge was rejuvenated for further use or the artefact was discarded. The greater the amount of work an edge is able to sustain the longer its use-life is and the greater its value to knappers who are limited by the amount of materials they are able to carry, or the availability of raw materials for artefact manufacture and use. Artefacts will necessarily
differ in the amounts of material they are able to remove or work in accordance with the amount of use to which they are subjected. In the following section, analyses proceed using cumulative material losses or cumulative cut depths as measures of performance. However, cumulative figures of material loss, or cut depth, are affected by the extent of use an artefact is capable of providing before being discarded (measured here in use durations of 200 strokes). As a result, before identifying the most productive combinations of features, it is first necessary to identify those artefacts with the longest and shortest use-lives.

As the criteria for removing an artefact from the study were different for sawing and scraping, survival was examined separately for the two actions. The data was analysed using survival analysis models which measure the probability that an artefact is functional at a given time and identify whether or not particular variables are correlated with rates of survival or failure times (Lawless 1982; Fox 2002; www.statsoft.com/textbook/stmtsurv.html#rcox_2003). Due to the likelihood that rates of survival/failure time are unlikely to have a normal distribution (as is required in straightforward multiple regressions) survival analyses more complex modeling to incorporate the effects of the hazard function (www.statsoft.com/textbook/stmtsurv.html#rcox_2003). The hazard function h(t) measures the infinitesimal risk of artefact failure within a short interval of time (t) given that the artefact meets minimal material loss requirements at time t. The survival function measures the probability that the artefact will be functional at a given time (Lawless 1982; Fox 2002). The most common regression model for investigating survival rates is the Cox proportional hazard model. In this model, the underlying hazard rate is assumed to be a function of the independent variables, rather than on any predetermined assumptions relating to the nature or shape of the underlying survival distribution (such as an exponential distribution). The proportional hazard model does however assume that given multiple individuals with differing values for the variables tested, the ratio of the estimated hazards over time will remain constant and thus 'proportional' (www.statsoft.com/textbook/stmtsurv.html#rcox_2003).

For each action tested experimentally, Cox proportional hazard models were fitted to examine which variables had a significant effect on artefact survival (longevity). All two-way interactions involving edge-plan, longitudinal profile, edge-angle, relief-angle (scraping experiments only) and contact material were included in the first ("full") model, and non-significant terms were removed sequentially. Plots of predicted survivor functions are
Kaplan–Meier estimates which provide the estimated survival function, based on the Cox models (Kaplan and Meier 1958; Lawless 1982; Fox 2002).

**Scraping**

Although 50% of the artefacts used in scraping activities failed during the study, neither the morphological variables nor contact material were found to have a statistically significant effect on artefact survival. It appears that artefact failure is either random, or not related, to the particular variables tested in this study for scraping wood.

Meaningful predictions of the ability of particular morphologies to survive with use in scraping activities cannot be made from my data set, and artefact failure is likely to be a random effect under these conditions. It does, however, represent an important avenue for future researchers to pursue.

**Sawing**

The following variables were found to have a statistically significant effect on artefact survival:

1. Contact material \( p<0.0001 \)
2. Plan \( p=0.011 \)
3. Edge-angle \( p=0.028 \)

Figures 51 and 52 plot artefact survival rates on hard and soft woods respectively, relative to plan and edge-angle. These figures, accompanied by Table 5, detailing calculated coefficients of these variables on proportional hazards models of the data, outline the effects of each variable on longevity.

Table 5. shows that the baseline hazard function is the hazard function for hard contact material, high edge-angle and concave plans. A positive coefficient indicates a greater likelihood that the artefact will fail. Relative to the baseline, it is clear that artefacts used on soft wood are much less likely to fail than those used on hard, with soft material having a lower hazard failure. Likewise, low edge-angles have a lower hazard for failure than high edge-angles. Both convex and straight edge-plans have a higher hazard for failure than concave plans, with straight plan the highest rate, followed by convex.
Figure 51. Predicted probabilities for artefact survival rates relative to edge-plan and angle on hard wood, when sawing.

Table 5. Estimated values of the coefficients of the explanatory values on fitting a proportional hazards model to the sawing data

<table>
<thead>
<tr>
<th></th>
<th>Coefficient (beta hat)</th>
<th>SE(beta hat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge-angle-Low</td>
<td>-0.947</td>
<td>0.437</td>
</tr>
<tr>
<td>Contact material - soft</td>
<td>-2.169</td>
<td>0.485</td>
</tr>
<tr>
<td>Plan - convex</td>
<td>0.455</td>
<td>0.508</td>
</tr>
<tr>
<td>Plan - straight</td>
<td>1.518</td>
<td>0.514</td>
</tr>
</tbody>
</table>

Failure rates on hard woods are high for all plan shapes and edge-angles. After 1200 strokes, less than half the number of artefacts that began the experimental cycle remained in use. After 1800, strokes less than a quarter are represented and after 2000 strokes straight edge-plans are no longer in use regardless of edge-angle. Failure rates were substantially lower on soft wood, with the most dramatic losses occurring on straight edge-plans with high edge-angles. At the end of the use-cycle a much larger proportion of all combinations of plan and edge-angle remain, with over 80% of concave plans with low edge-angles surviving to complete the experimental run of 2400 strokes.
On the basis of this information it is clear that on both woods, concave plans with low edge-angles are predicted to have the greatest rates of survival and therefore tend to have the longest use-life for the tool-user. These are followed closely by convex plans with low edge-angles. It is predicted that artefacts used to saw hard woods will fail earlier than those used to saw soft woods. The lack of effect of edge profile on artefact longevity means that these features, combined with any profile, tend to have similar use-lives.

**ARTEFACT PERFORMANCE**

One consequence of adopting an experimental protocol which uses all experiments for a minimum of 1200 strokes but which removes artefacts from the study when they are no longer achieving performance requirements, is that a number of combinations of morphological and use variables did not complete the 2400 stroke run, having been discarded earlier in the experimental run. Cumulative data is therefore missing for a number of morphological combinations that failed to complete the use-cycle. This means that data from the first 1200 strokes is more reliable than the second 1200 strokes. The low rates of artefact survival outlined in the discussion above meant that statistical analyses of artefact effectiveness could only be conducted on the first 1200 strokes of use. However, the substantially higher survival rates for scraping activities, coupled with the fact...
that none of the variables tested was found to significantly affect artefact longevity, meant that statistical analyses could include the entire use run with analyses performed separately for 100-1200 strokes and 100-2400 strokes. Plots of average effects over the full 2400 strokes are, therefore, accompanied by a table indicating the number of artefacts represented at each 200 stroke duration.

Analysis of the effect of use and morphological variables on artefact performance proceeds in two stages. The first examines average behaviours of each variable in isolation, comparing mean cumulative material loss/cut depth. Exploratory analysis of the mean response of each variable is graphed. Average effects mask any interactions that may be present but give an overall impression of variable behaviour. Variables include edge-plan, longitudinal profile, edge-angle, relief-angle (scraping experiments only) and contact material.

The second stage uses statistical analyses to identify variables, and interactions between variables, which have a statistically significant impact upon artefact effectiveness. In order to normalize the data as required for analysis, the log of cumulative material loss is used in all statistical analyses of artefact performance. The data is longitudinal in nature as measurements were taken on each artefact after every 200 strokes. In the analysis, a linear mixed model was fitted to the data using log cumulative material loss as the response variable. Plan, longitudinal profile, edge-angle, relief-angle, contact material and all two-way interactions and three-way interactions with duration were fixed effects with artefact as a random effect. Wald tests were used at 5% significance level, which are the appropriate tests in linear mixed models (Harrell 2001; Collett 2003). Non-significant terms were removed from the full model and estimates based on the reduced model. The fitted means for the statistically significant terms from the reduced model have been graphed, with least significant differences (lsd's) shown on each plot. If the difference between two means is greater than the corresponding lsd, that difference is statistically significant.

**SCRAPING**

The lower failure rates of artefacts used in scraping activities enabled statistical analyses up to 2400 strokes to be conducted on the data. While the data for the first 1200 strokes is still more complete than that of the later 1200 strokes, the absence of any significant effects or interactions between variables affecting artefact survival rates in scraping means that results generated from data at later stages of the cycle is still valid.
Edge-plan

Mean cumulative material loss for each edge-plan is graphed in Figure 53 and the accompanying information on the number of artefacts included in the generation of each mean (Table 6) shows that, at a general level, convex plans perform better than concave and straight edge-plans which tend to perform quite similarly throughout the use-cycles. The significance of these differences is discussed in detail in the following section.

Figure 53. Mean cumulative material loss according to edge-plan in scraping activities.

Table 6. Number of artefacts contributing to data points at each 200 stroke interval.

<table>
<thead>
<tr>
<th>Plan</th>
<th>100</th>
<th>200</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1000</th>
<th>1200</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2000</th>
<th>2200</th>
<th>2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>17</td>
<td>17</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Convex</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>22</td>
<td>18</td>
<td>16</td>
<td>14</td>
<td>14</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Straight</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>20</td>
<td>16</td>
<td>14</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Larger differences between the latter two plans are detected in the last 400 strokes of the cycle. However, much of this may be due to differences in the survival rates of artefacts with each edge-plan. For example, at 2400 strokes, mean cumulative material loss for concave plans is based on 16 samples while, for straight plans, only 10 samples are represented.

Longitudinal Profile

By comparison with edge-plans, minimal differences can be detected between the performances of different longitudinal profiles. Figure 54 and Table 7 suggest that each
profile follows a similar cumulative material loss curve. Convex and straight profiles perform at almost identical levels with concave profiles consistently performing to very slightly lower levels.

Figure 54. Mean cumulative material loss according to longitudinal profile in scraping activities.

Table 7. Number of artefacts contributing to data points at each 200 stroke interval.

<table>
<thead>
<tr>
<th>Profile</th>
<th>100</th>
<th>200</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1000</th>
<th>1200</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2000</th>
<th>2200</th>
<th>2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>19</td>
<td>17</td>
<td>15</td>
<td>12</td>
<td>12</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Convex</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>22</td>
<td>19</td>
<td>19</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Straight</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>22</td>
<td>19</td>
<td>17</td>
<td>14</td>
<td>14</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

**Edge-angle**

There are consistent differences between high and low edge-angles. Figure 55 and Table 8 shows that low edge-angles outperform high edge-angles throughout the experimental run, and slight differences in artefact survival rates likely to be affecting figures towards the end of the run.
Figure 55. Mean cumulative material loss according to edge-angle in scraping activities.

Table 8. Number of artefacts contributing to data points at each 200 stroke interval.

<table>
<thead>
<tr>
<th>Edge-angle</th>
<th>100</th>
<th>200</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1000</th>
<th>1200</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2000</th>
<th>2200</th>
<th>2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>31</td>
<td>26</td>
<td>24</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>32</td>
<td>29</td>
<td>27</td>
<td>24</td>
<td>24</td>
<td>22</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Relief-angle

The angle at which the artefact is held to the contact materials is found to have little or no effect on artefact productivity when examined in isolation from other variables. Figure 56 shows only one point of difference, at 1800 strokes, which is again likely to be due to artefact failure rates, which are outlined in Table 9.

Figure 56. Mean cumulative material loss according to relief-angle in scraping activities.
Table 9. Number of artefacts contributing to data points at each 200 stroke interval.

<table>
<thead>
<tr>
<th>Relief angle</th>
<th>100</th>
<th>200</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1000</th>
<th>1200</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2000</th>
<th>2200</th>
<th>2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>31</td>
<td>26</td>
<td>24</td>
<td>22</td>
<td>22</td>
<td>21</td>
</tr>
<tr>
<td>Low</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>32</td>
<td>29</td>
<td>27</td>
<td>19</td>
<td>19</td>
<td>18</td>
</tr>
</tbody>
</table>

Contact Material

Clear differences exist between the mean cumulative material loss by artefacts on each hardness of wood. Figure 57 and Table 10 detail these differences, in which soft wood is consistently removed in much larger amounts than hard wood throughout the experimental run.

![Figure 57. Mean cumulative material loss according to contact material hardness in scraping activities.](image)

Table 10. Number of artefacts contributing to data points at each 200 stroke interval.

<table>
<thead>
<tr>
<th>Contact Material</th>
<th>100</th>
<th>200</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1000</th>
<th>1200</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2000</th>
<th>2200</th>
<th>2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>31</td>
<td>27</td>
<td>26</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Soft</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>32</td>
<td>28</td>
<td>25</td>
<td>22</td>
<td>22</td>
</tr>
</tbody>
</table>

Having explored general trends in the behaviour of different variables upon mean productivity curves of cumulative material loss, the following discussion details the results of statistical analyses designed to determine how much of the differences detectable were statistically significant.
Statistical Analyses – Scraping, 100-1200 Strokes

In the first 1200 strokes all variables entered at least one statistically significant interaction. The following variables and interactions were identified as having a significant effect on edge productivity:

1. Edge-plan and duration ($p=0.003$).
2. Edge-angle and contact material ($p=0.010$).
3. Edge-plan and longitudinal profile ($p=0.032$).
4. Edge-angle and relief-angle ($p=0.037$).
5. Longitudinal profile and contact material with duration ($p<0.001$).

In each of the figures illustrating statistically significant interactions between variables, lines have again been drawn connecting the same variables in order to clarify connections between relevant variables; they do not indicate that intermediate measures exist between markers.

Edge-Plan and Duration ($p=0.003$)

Figure 58 plots predicted log cumulative material loss for each edge-plan over time. Convex plans consistently remove more material than either straight or concave, but a significant difference in cumulative material loss only exists between concave and straight plans, with this difference becoming greater with use duration. The two lsd’s on Figure 58

![Figure 58. Predicted log(cumulative material loss) for interaction between edge-plan and duration.](image-url)
predict significant differences between both edge-plans during the same use interval (the larger lsd) and for the same edge-plan in different intervals (the smaller lsd), showing differences over time and between edge-plans.

**Edge-Angle and Contact Material (p=0.010)**

Figure 59 details the difference in performance of high and low edge-angles with contact material hardness. Low edge-angles are predicted to be significantly more productive than high edge-angles on soft woods. However, on hard woods, both edge-angles are predicted to perform at a similar level, with low edge-angles significantly more productive on softer wood than on harder wood. These differences between edge-angle and contact material persists with use duration.

![Figure 59. Predicted log(cumulative material loss) for the interaction between edge-angle and contact material hardness.](image)

The best combinations of edge-angle and contact material are therefore predicted to be low edge-angles on soft wood, while either edge-angle is equally suitable for working hard woods.

**Edge-Plan and Longitudinal Profile (p=0.032)**

The interaction between edge-plan and longitudinal profile is illustrated in Figure 60. From the diagram it is predicted that greatest log(cumulative material loss) occurs with the plan/profile combinations of convex/straight, concave/straight and straight/convex. Differences between the performances of these three combinations are not significant.
Morphology and Function – Experimental Results

Chapter 8

Concave profiles are predicted to consistently perform poorly regardless of plan. Conversely, straight profiles achieve much greater material loss when combined with either a concave or convex plan than with a straight plan. It is predicted that concave plans perform significantly better when combined with a straight profile, while longitudinal profile has no effect on convex plans. Straight plans perform significantly better with a convex profile than either concave or straight profiles. In almost every case it is better to choose an edge in which plan and profile differ in shape, while all combinations of the same shape predicted to perform quite poorly. Convex/convex combinations are the obvious exception with profile having no effect on convex plans.

![Figure 60 Predicted log(cumulative material loss) for the interaction between edge-plan and longitudinal profile.](image)

For prolonged use, the best combinations of plan and profile respectively are therefore concave/straight, convex/straight and straight/convex, all of which perform to much the same level. These interactions persist with duration.

**Edge-Angle and Relief-Angle (p=0.037)**

The interaction between edge-angle and relief-angle is detailed in Figure 61. It indicates a statistically significant difference between high and low edge-angles is predicted only if relief-angle is low. Although there are large differences between the performance of both low and high edge-angles with changes in relief-angle, these were not found to be statistically significant.

The best combination of edge-angle and relief-angle is therefore predicted to be low edge-angle with a low relief-angle. In general, a high edge-angle will perform better at a high
relief-angle than at a low one. A low relief-angle is better suited to a low edge-angle than to a high edge-angle.

![Figure 61 Predicted log(cumulative material loss) for the interaction between edge-angle and relief-angle.](image)

**Longitudinal Profile and Contact Material with Duration (p<0.001)**

The interaction between longitudinal profile and contact material with duration is illustrated in Figure 62. Contact material has a strong effect on log(cumulative material loss) with concave profiles. These are predicted to be significantly more productive on soft wood than on hard throughout all use durations. Convex and straight profiles perform significantly better than concave profiles throughout the use-cycle on hard wood. On soft wood, however, profile has no effect on cumulative material loss. The best combination of edge profile and contact material is therefore convex or straight on hard woods and any edge profile on soft wood.

**StatisticalAnalyses – Scraping, 1200-2400 strokes**

Over the next 1200-2400 strokes, variables and interactions changed slightly, probably as a consequence of differing artefact survival rates and changes to the shape of the working edge by use-induced edge scarring (discussed in a later chapter). Nevertheless, the following variables and interactions were identified as having a significant effect on artefact productivity:

1. Edge-plan and longitudinal profile with duration (p=0.003).
2. Longitudinal profile and contact material with duration (p=0.015).
3. Edge-angle and contact material (p=0.018).

![Graph showing predicted log(cumulative material loss) for different edge-angles and material combinations with duration.]

Figure 62. Predicted log(cumulative material loss) for the interaction between longitudinal profile and contact material with duration.

Edge-plan and Longitudinal Profile with Duration (p=0.003)

Interactions between edge-plan and longitudinal profile with duration are graphed in Figure 63. For the entire use-cycle only slight differences are predicted between the performances of various combinations.

The pattern for plan/profile combinations remains the same as in the first 1200 strokes with one exception. Convex edge-plans change slightly over time with convex/convex combinations predicted to increase in productivity from 1600 strokes onwards. This increase in effectiveness makes convex/convex and convex/straight plan/profile combinations equally effective at 1600 strokes.

With the increase in effectiveness of convex/convex profiles from 1600 strokes onwards, the best combinations of plan and profile respectively are predicted to be concave/straight, convex/straight and straight/convex and convex/convex.
Longitudinal Profile and Contact Material with Duration \((p=0.015)\)

The interaction between longitudinal profile and contact material and the differences in these interactions over the full 2400 strokes, is outlined in Figure 64. The interaction changes very little between the 100-1200 stroke and 100-2400 stroke analyses. Concave profiles are predicted to continue to perform better on soft wood than on hard while convex and straight profiles continue to perform significantly better than concave on hard wood. On soft wood, however, the effects of various profiles are predicted to change over time.

At 1400 strokes, soft wood had no effect on profile and no significant differences are detectable between the predicted performances of each profile. However, by 1600 strokes, convex profiles appeared significantly better than concave profiles with straight profiles performing at levels between the two and not significantly different to either. At 1800 strokes and up to 2400 strokes, convex profiles were significantly better than both straight and concave profiles, both of which performed to similar levels.
In most cases, a convex or straight profile is predicted to be most productive on hard woods, while on soft woods, profile does not become important until much later in the use-cycle. From 1600 strokes onwards, a convex profile is the best edge shape for scraping soft wood.

**Edge-Angle and Contact Material (p=0.018)**

The interaction between edge-angle and contact material remains the same throughout the entire use-cycle as is illustrated in Figure 64 below. The best combinations of edge-angle and contact material are therefore predicted to be low edge-angles on soft wood, and either low or high on hard wood. The loss of the interaction between edge-angle and relief-angle in these later stages of the cycle may be due either to a blurring of relief-angles through increased scarring with use, or to differential rates of fall out in artefact survival.

**Summary**

Combining the best of each of these variables again indicates that ideal morphologies exist for each action and contact material. Both contact materials are predicted to be worked best with convex plans. The advantages of straight and convex profiles on hard woods and
the advantage of mixing convex plans with straight profiles indicate that a convex/straight plan/profile combination achieve highest performance levels on hard woods. On softwoods, it is predicted that convex/straight profiles are also ideal for the first 1200 strokes, however convex profiles become higher performers over time suggesting that for longer term use, a convex/convex plan/profile combination perform best on soft woods.

On hard woods, either edge-angle will be productive when combined with the same relief-angle as edge-angle used, while on soft wood, it is predicted that low edge-angles used at a low relief-angle are ideal. Hard wood will, therefore, be best worked with a convex/straight plan profile and high/high or low/low edge-angle/relief-angle combination. On soft woods, convex/convex plan profile combined with low/low edge-angle/relief-angle mix are predicted to be ideal.

SAWING

Restrictions associated with both the mechanization of experimentation and the need to keep pressure constant throughout the experimental program prohibited, respectively, the ability to saw through specimens and the increase of pressure over time (see discussion on experimental design in Chapter 6). As such, experiments comprised the creation of a series of grooves which allowed calculations of decreasing cut depth over time to be made on a smaller scale. To some extent, the effects of variables, such as edge-angle and longitudinal profile, will be limited by the inability of artefacts to penetrate very deeply into the material. In terms of creating grooves, however, and establishing a limited understanding of the role of edge-angle in sawing effectiveness, the study is adequate.
Edge-Plan

Mean cumulative cut depths for each edge-plan are plotted in Figure 66 and Table 11 indicates the number of artefacts contributing to calculations of mean cut depth at each use interval. Convex and concave edge-plans perform at similar levels and both perform better than straight edge-plans. Differences between the performances of edge-plans become more enhanced after 1200 strokes. Dramatic differences in the survival rates of edge-plans contribute to much of the variation in the performance of plans in the final 1200 strokes.

Figure 66. Mean cumulative cut depth according to edge-plan in sawing activities.

Table 11. Number of artefacts contributing to data points at each 200 stroke interval.

<table>
<thead>
<tr>
<th>Plan</th>
<th>100</th>
<th>200</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1000</th>
<th>1200</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2000</th>
<th>2200</th>
<th>2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Convex</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Straight</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Longitudinal Profile

Mean cumulative cut depths for each edge profile are outlined in Figure 67, with details of the number of artefacts included in each measurement in Table 12.

Table 12. Number of artefacts contributing to data points at each 200 stroke interval.

<table>
<thead>
<tr>
<th>Profile</th>
<th>100</th>
<th>200</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1000</th>
<th>1200</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2000</th>
<th>2200</th>
<th>2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Convex</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Straight</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
Differences between longitudinal profiles in sawing activities are virtually identical up to 1800 strokes, after which, the effectiveness of straight profiles continue to decline in productivity at a steady rate while convex and concave profiles remain slightly more productive. During the first 1200 strokes, no differences between profile performances are detectable.

**Edge-Angle**

Illustrating mean cumulative cut depths for each edge-angle, Figure 68 shows a general trend for low edge-angles to penetrate deeper than high edge-angles up to 1800 strokes. Thereafter, the performance of edge-angles is interchangeable; a likely product of high artefact drop-out rates (see Table 13).
Table 13. Number of artefacts contributing to data points at each 200 stroke interval.

<table>
<thead>
<tr>
<th>Edge-angle</th>
<th>100</th>
<th>200</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1000</th>
<th>1200</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2000</th>
<th>2200</th>
<th>2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Contact Material

Differences in cumulative cut depths are clear throughout the experimental run with artefacts used in sawing hard versus soft wood, as is shown in Figure 69. Regardless of any other factors, deeper cuts are obtained in soft woods than in hard woods with none of the artefacts used to saw hard wood continuing past 2000 strokes (see Table 14).

![Figure 69. Mean cumulative cut depth according to edge-angle in sawing activities.](image)

Table 14. Number of artefacts contributing to data points at each 200 stroke interval.

<table>
<thead>
<tr>
<th>Contact Material</th>
<th>100</th>
<th>200</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1000</th>
<th>1200</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2000</th>
<th>2200</th>
<th>2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Soft</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>14</td>
<td>14</td>
<td>13</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Statistical Analyses – Sawing, 100-1200 Strokes

Statistical analyses for artefact performance in sawing activities is necessarily confined to the first 1200 strokes of use due to depletion of data by high failure rates from 1200 strokes onwards. Lines have been drawn connecting the same variables in each of these figures in
order to clarify connections between relevant variables; they do not indicate that intermediate measures exist between markers.

In the first 1200 strokes the following interactions had a significant effect on artefact productivity:

1. Edge-plan and contact material \((p=0.042)\).
2. Edge-plan and edge-angle with duration \((p=0.045)\).

Longitudinal profile did not have a significant effect on \(\log(\text{cumulative cut depth})\) either alone or as part of an interaction.

**Edge-Plan and Contact Material \((p=0.042)\)**

The interaction between plan and contact material illustrated in Figure 70 shows that all plans are predicted to perform significantly better on soft woods than on hard. Concave plans perform significantly better on hard wood than both convex and straight, while concave and convex plans perform significantly better on soft woods than do straight plans. Concave plans are therefore predicted to be the best for use on hard wood, while concave or convex plans are predicted to be equally productive on soft wood in sawing activities.

![Figure 70. Predicted log(cumulative cut depth) for the interaction between plan and contact material in sawing activities.](image-url)
Morphology and Function – Experimental Results

Chapter 8

Edge-Plan and Edge-Angle with Duration (p=0.045)

The nature of the interaction between effect of plan and edge-angle on log(cumulative cut depth) varies with duration in sawing activities. Figure 71 shows mean log (cumulative cut depth) for each edge-plan and edge-angles over time.

Variations in edge-angle were not found to affect the log(cumulative cut depth) attained by concave plans. By comparison, convex plans are predicted to perform significantly better when combined with a low edge-angle than a high edge-angle. Edge-angles perform similarly with straight plans in the first 200 strokes, after which low edge-angles are predicted to be significantly more productive than high edge-angles. Throughout the experimental run, convex and straight edge-plans perform similarly and are both more productive than concave edge-plans where edge-angles are high, while the performance of low edge-angles varies with edge-plan over time.

Figure 71. Predicted log(cumulative cut depth) for the interaction between plan and edge-angle with duration in sawing activities.

The best performing combination of edge-plan and angle over the 1200 strokes is convex/low. However, where the edge-angle is high, convex and concave edges are predicted to perform equally well. By comparison, the performances of edge-plans vary with time on low edge-angles. In most cases throughout the experimental run, convex plans are the best, followed by concave and, finally, straight plans.
Summary

Statistical analyses of the study data reveal a number of significant variables and significant interactions between variables influencing artefact effectiveness in sawing activities. The results presented here indicate that, of the edge variables studied, the plan/edge-angle combination found to produce greatest cut depths is convex/low, regardless of contact material. However the interaction between plan and contact material predicts that concave plans perform best on hard wood and concave and convex plans are equally effective on soft wood. The previous discussion on edge longevity identified concave/low plan/profile combinations as having the highest survival rates, closely followed by convex/low combinations. In sawing activities, the knapper is presented with a choice whereby either longevity or effectiveness can be maximized. The higher performance levels of convex/low combinations on soft woods are accompanied by a slightly higher risk of artefact failure than the slightly lower performing concave/low alternative. On hard wood, however, no such decision is required with concave plans experiencing both the lowest rates of failure and the highest levels of cumulative cut depths.

One problem with the use of concave plans in sawing is that, while they perform well quantitatively and survive well long-term, qualitatively they are extremely poor. The mechanization of use in these experiments enabled each artefact to be continually returned to the same position for multiple use durations. However, lining up both points of contact on concave edges was still difficult. It therefore seems possible that, when used under less controlled circumstances, aligning both points might be impossible and use of concave plans will result in parallel lines produced by each of the two points of contact. Qualitatively, the best grooves, in terms of the neatness/crispness of the edges, were produced by a convex profile, which, when combined with a low edge-angle, was also a high performing combination. It seems unlikely that a knapper would choose a combination that was difficult to use and produced a messy outcome, but was long lasting, in favour of an easily used, well performing alternative that had a slightly higher risk of long term failure. It is therefore the case that convex/low combinations represent the best performing combination on both contact materials and with fairly sound survival rates. The absence of longitudinal profiles in interactions relating to effectiveness or longevity means that convex/low plan/edge-angles with any combination of profile will perform equally effectively.
CONCLUSIONS

Whilst it must be remembered that the results generated from the highly controlled experimental program conducted in this thesis are somewhat removed from real-life hunter-gatherer activities, they do have important implications for understanding the relationship between artefact form and function. The results presented in this chapter may be broadly divided into the following five primary observations relating form to function.

Certain features, and combinations of features, incur functional advantages on working edges. That is, some morphologies produce greater cumulative material loss/cut depths than others for each action and for each contact material. All else being equal, in sawing activities certain combinations of plan and edge-angle will give the tool user a greater number of productive strokes than will others for each contact material.

As those variables which contribute to levels of cumulative material loss/cut depth are different from those found to increase chances of survival, in some cases the tool-user may have to decide which aspects of tool performance he wishes to maximize. Subject to individual circumstances, a tool-user may choose to maximize durability at the expense of performance or to capitalise on performance at the expense of long-term useability.

While advantageous morphologies do occur, the random effect of survival of artefacts used in scraping activities and the absence of longitudinal profile as a significant variable on log(cumulative cut depth) indicates that in some cases, morphologically dissimilar forms (e.g. differing longitudinal profiles) may be found to represent functional equivalence. Likewise, it is possible that, within a particular number of strokes (up to 2400 strokes only were tested in this experimental program), all forms used in scraping activities are equally likely to fail, regardless of number of strokes performed.

Each of these differences in performance and longevity between different edge-forms occurs at the level of individual edges. Differences in the overall morphology of the experimental tools used did not change the ability of individual edges to perform in a certain way, provided the functional edge possessed the right combination of morphological features. While this may not be true of all forms and activities, within the confines of this research program, the performance of individual artefacts in sawing and scraping activities was dependent upon individual edge morphologies.
Finally, the discovery of differential survival rates between edges used on hard and soft woods implies that more artefacts/edges will be required to saw a piece of hard wood than will be required to saw a piece of soft wood of equal size.

While direct comparisons should not be made between highly controlled experimental data such as this and the archaeological record, each of these observations has important consequences for future investigations into interpretations of stone artefact function. As certain combinations of features perform better than others, this suggests that a visible relationship may sometimes exist between morphology and function. However, this relationship cannot be regarded as straightforward, with morphologically dissimilar combinations of features found to perform equally well in sawing tasks. Likewise, the ability for particular features to enhance the number of strokes able to be performed means that some morphologies may represent a compromise in the qualities of performance and longevity. Further complicating the issue is the possibility that, for several artefact functions, it is the working edge, rather than the morphology of the entire artefact, that contributes to performance. This means that, in an archaeological context, artefacts that appear on the whole to be similar may have been suited to, and used in, entirely different tasks. Likewise, artefacts that appear morphologically dissimilar may be identical in the functional attributes of the working edge that matter and perform very similarly. These results imply that, in some circumstances, direct correlations between form and function may be difficult, if not impossible, to make. A final implication relates to the differential use-lives of artefacts used in different activities. The comparatively shorter use-life of artefacts used in sawing activities, compared to those used in scraping activities, suggests that a larger number of artefacts will be required to complete the same number of strokes when sawing than when scraping. As such, differences in the proportions of activities represented in an archaeological assemblage may not necessarily indicate differences in the amounts of a particular activity conducted, but rather differential survival rates of the edges used. These results lead to concerns about how archaeologists currently view the relationship between artefact performance and morphology and its identification in the archaeological record.

In the following chapter, the ability to enhance an edge’s performance, by combination with other advantageous features noted in these results, is discussed in more detail. If it is possible to enhance an edge’s performance by combining the right morphological and use variables, it is also possible to hinder performance by combination with poor performing
features. Chapter 9 explores any compromises and trade-offs which may occur by a tool user selecting for one variable over another.
INTRODUCTION

The previous chapter identified the important morphological and use variables that contribute to artefact performance. From the results presented it was clear that, subject to the particular combinations of morphological features an artefact possesses, performance may either be enhanced or hindered. This chapter continues to focus on these important variables by exploring the possibility that compromises and trade-offs exist between forms. For example, is it possible to offset the relatively poor productivity of a straight edge plan by combining other productive variables? What is the cost to time and productivity levels by compromising on the features used in given tasks?

EXPLORING TRADE-OFFS

As in the previous chapter, scraping and sawing activities are discussed separately. In addition, examination of trade-offs and compromises for each activity will be divided into two parts. The first part of the discussion focuses on trade-offs between the significant effects and two-way interactions between the variables identified in the previous chapter. Due to the fact that statistical analyses examined a maximum of two way interactions and two-way interactions with duration, the statistical effects of combinations of all variables, that is plan, profile, edge-angle, relief-angle and contact angle, are not examined. In the second part of the discussion, the combined effects of all five variables are explored. By identifying observable trends in multiple combinations of these features it is possible to define how much compromise may be made in artefact form before performance is also compromised. In cases where the highest performing choices are simply unavailable, performance may come at a cost to the tool user, both in time and productivity.

The following discussion attempts to quantify the ramifications of adopting combinations of features that are lower performing alternatives to the tool user. However, it is important to remember that the specific quantities and measurements discussed here are only relevant within the experimental system; they do not represent ‘real world’ situations and cannot be directly compared as such. Observed levels of difference in the performance of edges with different morphological features were often quite small, in some cases differences in
log(cumulative material loss) may be less than a gram and differences in log(cumulative cut depth) may be less than 1mm. For purpose of this experiment, it is not the scale of difference that is important, but rather the fact that differences exist and that they are measurable. It is the implications of these results, rather than the specific figures generated, that are of value to archaeologists. Controlled experimental analyses allow more in depth explorations to be undertaken of various processes in order to identify areas of research which may have been over looked, or misinterpreted, in less controlled analyses. Their results serve as a guide for more detailed analyses in important areas of interest under circumstances that are more directly comparable with the situation being explained, such as the archaeological context.

Scraping

In the previous chapter the following interactions were identified when statistical analyses were conducted for the first 1200 strokes:

1. Edge plan with use duration \( (p=0.003) \).
2. Edge-angle and contact material \( (p=0.010) \).
3. Edge plan and longitudinal profile \( (p=0.032) \).
4. Edge-angle and relief-angle \( (p=0.037) \).
5. Longitudinal profile and contact material with use duration \( (p<0.001) \).

**Plan and Use Duration** \( (p=0.003) \)

The first of these interactions; between plan and use duration, was the most significant of the two-way interactions identified. Convex plans were predicted to always be more effective, followed by concave and finally, straight plans, and that the differences in performance levels increased with use duration. This means, for example that not only do straight and concave plans fail to reach the cumulative material losses achieved by convex plans, but that even lower levels of productivity are predicted to take substantially longer to achieve by using either a concave or straight edge plan. Figure 58 (Chapter 8, pg 189) illustrated average log(cumulative material loss) relative to edge plan over time. From this figure it is possible to translate log(cumulative material loss) into differences in performance over time. For example, a log(cumulative material loss) of 0.84g was achieved by convex plans after 600 strokes. By comparison, it takes approximately 870 strokes for
Compromises and Trade-Offs Chapter 9

Concave plans to remove 0.84g, and it takes a straight plan 1200 strokes to achieve the same level of cumulative material loss as is achieved by a convex plan after 600 strokes. The selection of a straight or convex plan in preference to a convex plan therefore results in a cost in both time and energy to the knapper, of up to double that required for a convex plan.

**Edge-Angle and Contact Material** (p=0.010)

Another option for enhancing low performing features is through edge-angle. Significant differences exist in the predicted mass loss of worked material between high and low edge-angles on soft wood. Low edge-angles produce 0.28g greater log(cumulative material loss) on soft wood than high edge-angles. Using the productivity curve for convex edge plans outlined in Figure 59 (pg 189), a low edge-angle on soft wood is predicted to require only 130 strokes to produce the same levels of log(cumulative material loss) as a high edge-angle would produce in 200 strokes. This difference increases with use duration so that only 530 strokes are required for a low edge-angle to produce material losses equivalent to those generated by high edge-angle after 1200 strokes. When working soft wood a low edge-angle can perform the same task as a high edge-angle in almost half the time.

The effect of edge-angle on soft material is such that, in some cases, straight plans may produce higher or equal rates of log(cumulative material loss) as convex plans, if the straight plan is coupled with a low edge-angle and convex plans with a high edge-angle. On soft material, edge-angle is predicted to have the ability to greatly enhance the performance of a working edge. On hard material, both edge-angles perform to similar levels.

**Plan and Longitudinal Profile** (p=0.032)

It is, however, possible to enhance the performance of any plan by combining it with a suitable longitudinal profile. The interaction between plan and longitudinal profile illustrated in Figure 60 (see pg 190) predicts that, for each plan, there exists a longitudinal profile combination to which it is best suited and attains highest performance levels. Concave and convex plans perform best when combined with straight longitudinal profiles and straight plans perform best when combined with convex longitudinal profiles. The enhancement of straight and concave plans by combination with appropriate profiles is such that the differences between the performances of these three combinations are not statistically significant.
Where highest performing combinations of plan and profile cannot be obtained compromise is inevitable. When combined with convex and straight longitudinal profiles, log(cumulative material loss) for concave plans is predicted to reduce by an average of 0.2g and 0.32g respectively at any duration. Referring to average log(cumulative material losses), it is possible to approximate the cost (concave plans outlined in Figure 60) to the knapper in terms of stroke number. Due to the fact that rates of material loss tend to decline with use duration for each edge plan, the effect of any loss in log(cumulative material loss) will differ according to which use duration the loss is measured against. Differences were smaller in the earlier stages of the experimental run but increased and become amplified over time. For example, a loss of 0.2g in log(cumulative material loss) with a concave/convex plan/profile combination, resulted in an average difference of only 100 strokes in the first 200 stroke period but increased to a difference of 500 strokes worth of productivity towards the end of the experimental run (around 1200 strokes). As such, the decision to utilise a concave/convex combination is predicted to cost the knapper an average of 500 strokes, achieving the same levels of log(cumulative material loss) after 1200 strokes as could be achieved from 700 strokes using a concave/straight combination. The greater loss of 0.32g log(cumulative material loss) associated with concave/concave plan/profile combinations, differs significantly from the loss recorded for concave/convex combinations. Suffice to say, the set backs to a knapper forced to use this combination over the other two would be even greater.

Similarly, where straight plans are combined with straight and concave profiles log(cumulative material loss) is predicted to be lower by an average of 0.4g in both cases. This loss is substantial for straight plans, with the effect on productivity ranging between approximately 250 strokes in the first 400 strokes of the experimental run and 800 strokes towards its end. The decision to utilise straight edge plans with any profile other than convex will require the knapper to perform 1200 strokes to achieve the same material loss as could be attained after 400 strokes with a straight/convex plan/profile combination. All else being equal, the use of alternative combinations is predicted to require up to three times the time and effort needed by straight/convex combinations.

Convex plans suffer to a much lesser degree due to their ability to attain high performance levels. However, the combination of convex plan with convex or concave profiles is predicted to result in a log(cumulative material loss) of between 0.18g and 0.28g respectively; the difference between them is not significant. As a result, the effect on productivity ranges between approximately 50 strokes in the first 200 stroke period and 500
Compromises and Trade-Offs

Chapter 9

strokes towards the end of the experimental run. Again, the decision to utilise convex or concave profiles with straight plans results in heavy losses in time and energy, requiring 1200 strokes to achieve the same levels of log(cumulative material loss) as could be achieved by a convex/straight combination after 700 strokes.

Convex plans is are predicted to experience slightly more rapid decline in log(cumulative material loss) with use duration than concave edges. However the effects of combining either plan with less than ideal profiles results in similar set backs as far as stroke number is concerned. Combination of both these plans, with concave or convex profiles, is predicted to require an extra 500 strokes to achieve losses equivalent to their combination with straight profiles.

At a more general level the strength of the effect of plan on log(cumulative material loss) is such that both concave and convex profiles is predicted to perform to a higher level when combined with a convex plan. The greatest performance enhancement in removing material is provided by combining a poorly performing profile with a convex plan.

Edge-Angle and Relief-Angle (p=0.037)

While low edge-angles can be easily made higher through edge damage generated by use, or deliberate retouch and resharpening of the edge, it can be difficult to make them lower without sacrificing large amounts of raw material. In situations where raw material is limited and efforts are being made to conserve available resources, hunter-gatherers may be forced to use high edge-angles. In the experimental process it is predicted that performance levels of high edge-angles could be enhanced by adjusting the relief-angle at which the working edge is held. While the differences between the performance of high edge-angles at high and low relief-angles was not statistically significant, it was clear that, in general, the log(cumulative material loss) of high edge-angles was greater by 0.15g if the edge was used at a high relief-angle. Using the productivity curve for convex plans displayed in Figure 61 (pg 191) as an example, it can be extrapolated that using a high edge-angle at a high relief-angle will allow the same removal of equivalent log(cumulative material loss) at 750 strokes as could be removed by the same edge held at a low relief-angle.

It was predicted that the performance of low edge-angles could also be enhanced by relief-angles, performing significantly better when used at a low relief-angle than with a high relief-angle. Log(cumulative material loss) averaged 0.3g higher when low edge-angles were
used at a low relief-angle than at a high relief-angle. This effect on convex plans equated to a gain of 650 strokes with similar productivity levels reached after 550 strokes at low relief-angles as that attained after 1200 strokes with high relief-angles.

The large size of the LSD evident for this interaction (see Figure 61, pg 191) is likely to be due, in part, to the fact that throughout the experimental run the removal of flakes, through use damage, constantly changed the relief-angle being applied specifically to the working edge. As a result, clear differences between high and low relief-angles became slightly blurred as use increased, and scarring occurred. This resulted in a higher degree of variability in the responses to the two categories which, over time, became less well-defined and, instead, fell within a range of degrees throughout use.

**Longitudinal Profile and Contact Material with Use Duration** (p<0.001)

The interaction between longitudinal profile and contact material affords an option to enhance the performance of particular combinations by utilizing it on more appropriate materials. Figure 62 (pg 192) predicted indicates that, while differences do not exist in the performance of straight profiles regardless of wood hardness, concave profiles differ dramatically. Concave profiles are predicted to be generally low performers, except where combined with a straight plan, such that options for enhancing the performance of concave profiles are more limited than for others. Log(cumulative material loss) is increased by almost 0.32g when concave profiles are used to work soft wood rather than hard. As such, where use of a concave profile is unavoidable, greatest productivity would be achieved by using the softest wood available to the tool-user while still fulfilling his/her functional needs. The levels of log(cumulative material loss) produced by concave profiles after 1200 strokes on hard wood can be produced after only 400 strokes on soft wood.

Convex profiles also show slight variations in log(cumulative material loss) on different contact materials with use duration. Differences between the performance of convex profiles on harder and softer wood are predicted to occur after 1000 strokes, during which time convex plans are predicted to remove 0.15g more log(cumulative material loss) on softer wood than they do on harder wood. As a result, convex profiles produce the same levels of productivity on harder wood at 1200 strokes as they do on softer wood at 800 strokes.

There are, however, obvious limits to how often an artefact can be enhanced by adjusting the contact material worked. In most cases, the worked material is the priority of the task
Compromises and Trade-Offs

and compromising on material is simply not an option. However, in situations where retooling is difficult and a limited number of artefacts and working edges are being relied upon for a range of activities, it would be more effective to utilise generally low performing concave profiles on soft woods.

Summary

These results suggest two important aspects of tool use for archaeologists to consider. The first is that an inability to manufacture a tool with the highest performing combinations of morphological features, for whatever reason, may result in the tool user incurring a number of associated costs. The measurement of performance and longevity by total mass of material removed, or total cut depth against number of strokes in this experimental program means that discussions of costs are necessarily calculated in a similar way; that is the number of strokes required to remove a particular total mass or cut depth. The extent to which these costs might be considered problematic or prohibitive will depend upon circumstance and upon which variables (ie plan, profile etc) have had to be compromised. Where variables interacted with duration, the costs to the tool-user become greater with continued use. Assuming a constant stroke rate, the increase in number of strokes required to remove a particular total mass or cut depth equates to an increase in the time and energy required by the tool user to accomplish his task, and may also require the manufacture of additional tools to complete the same task that a tool with a higher performing combination of features might have been able to complete in its entirety.

The second aspect is that relatively poor performing features may be enhanced and associated costs minimized, by combining them with other higher performing features. Inadequacies in one of the variables contributing to artefact performance may sometimes be compensated for by others. This meant that similar performance levels were attained by a wide variety of morphological and use variables, though always at a lower level than those attained by combinations representing the highest performing features of each variable. As such, if the highest performing options were not available, a much wider range of variables were capable of performing to the same, slightly lower, level.

In the following section, the combined effects of significant variables upon the overall performance levels of an edge are discussed. As variables are, in many cases, noted to act differently depending upon contact material hardness, the performance levels of scraping artefacts on each wood hardness are discussed separately.
Combined Effects

The nature of this data means they are not susceptible to general statistical methods for comparing the combined effects of multiple variables. However, the purpose of comparisons between the combined effects of significant variables here is to show which combinations of features remove the most material, and how compromises in features affect the overall performance of individual forms. This can be achieved by looking at the relative rankings of different morphologies as a way of putting in order the performances of different forms.

Scraping Hard Wood

The ability of individual variables, or combinations of variables, to enhance or compensate for inadequacies in others means that different combinations of morphological features are capable of performing to equally high levels. By listing each of the artefacts from most, to least, productive relative to duration and raw material it is possible to identify the most productive forms and to characterise the balance of features contributing to artefact success. It is also possible to monitor changes in productivity over time and identify those artefacts that perform better over the long-term relative to those that are better in short-term usage. It is again important to note that in the following discussion the scale of difference between the performance of various artefact morphologies is often extremely small. The purpose of the following discussion is to highlight the complexity of the relationships between artefact morphology and use and to illustrate that, under controlled circumstances, differences exist in the performance of artefacts that can be accounted for by variations in artefact features. It is not an assertion that these differences would be noted or be directly applicable to 'real life' situations.

The six most productive combinations of features at 100, 400, 800 and 1200 strokes on hard woods are detailed in Table 15 below. The table shows that from 100 strokes onwards a combination of convex/straight, high edge-angle and high relief-angle is the most productive form for scraping hard wood. However, after the exceptionally high performance of this combination, differences between the performances of the next 5 highest performing artefacts are ordinal. Slight fluctuations in performance are visible with use duration. The SVHH combination, positioned first in the first 100 strokes, declined to fourth over the 1200 strokes. A slightly higher rate of decline is noted for fourth ranked SVLL which after 400 strokes falls from a position in the top six, while a more dramatic
rate of decline is noted for sixth combination SVHL which disappears from these highest performers after the first 100 strokes.

Table 15. Morphologies for most productive artefacts for scraping hard wood (mean cumulative material loss)

<table>
<thead>
<tr>
<th>Position</th>
<th>100</th>
<th>Material Loss (g)</th>
<th>400</th>
<th>Material Loss (g)</th>
<th>800</th>
<th>Material Loss (g)</th>
<th>1200</th>
<th>Material Loss (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SVHH</td>
<td>2.90</td>
<td>VSHH</td>
<td>9.73</td>
<td>VSLL</td>
<td>16.88</td>
<td>VSHH</td>
<td>21.83</td>
</tr>
<tr>
<td>2</td>
<td>VSHH</td>
<td>2.72</td>
<td>SVHH</td>
<td>8.89</td>
<td>VSLL</td>
<td>13.06</td>
<td>VSHH</td>
<td>16.90</td>
</tr>
<tr>
<td>3</td>
<td>CSII</td>
<td>2.47</td>
<td>VSHH</td>
<td>8.27</td>
<td>CSII</td>
<td>12.56</td>
<td>CSII</td>
<td>16.78</td>
</tr>
<tr>
<td>4</td>
<td>SVLL</td>
<td>2.17</td>
<td>CSII</td>
<td>7.53</td>
<td>SVHH</td>
<td>12.39</td>
<td>SVHH</td>
<td>15.81</td>
</tr>
<tr>
<td>5</td>
<td>VSHH</td>
<td>2.11</td>
<td>SVLL</td>
<td>6.88</td>
<td>VSHH</td>
<td>11.58</td>
<td>SVLL</td>
<td>14.98</td>
</tr>
<tr>
<td>6</td>
<td>SVHH</td>
<td>1.92</td>
<td>VSHH</td>
<td>6.68</td>
<td>VSHH</td>
<td>10.43</td>
<td>VSHH</td>
<td>13.88</td>
</tr>
</tbody>
</table>

Initials in order indicate plan, profile, edge-angle and relief-angle. Key: S= straight, V= convex, C= concave, H= high, L= low

By comparison, combinations VSLL, VSHL and VVHH experienced solid rates of increase in material loss with duration. Combination VSLL positioned fifth after 100 strokes and second after 1200 strokes while combinations VSHL and VVHH do not position within the top 6 forms until 400 and 800 strokes respectively. Differential rates of decline and increase in material loss were responsible for fluctuations of position within the six most productive forms. These differential rates in cumulative material loss means that certain combinations of features are more advantageous over the long-term while others are better suited to short term use. For example, the long term benefits incurred by choosing either VSHL or VSLL combinations will only be realized after 400 strokes. Comparatively, SVLL combinations, despite declining rates of material loss over time, perform better over the first 400 strokes than either VSHL or VSLL.

While the top two ranking combinations after 1200 strokes - VSHH and VSLL – represent the combinations of plan, profile, edge-angle and contact angle identified experimentally as being the best performing features, it is interesting to note that, within these highest ranked combinations, several represent compromises in features. Fifty percent of these artefacts utilise a straight/convex plan/profile combination, with the poor performance of straight plans offset by combination with highest performing convex profiles. Edge-angle and relief-angle combinations are then responsible for the order of rankings within artefacts with the same plan and profile. High/high combinations attain greater masses of material loss than low/low combinations (on hard wood) which, in turn, attain higher masses of material loss than high/low mixtures. The result in each of these cases is decline in productivity with use duration. The SVHH combination shows gradual decline and the ability to maintain substantial cumulative material losses. The lower performing SVLL
Compromises and Trade-Offs Chapter 9 shows a more rapid rate of decline and SVHL more rapid again, resulting in their removal from the highest performers at 400 and 100 strokes respectively. By comparison, VSHL and VVHH combinations increase in rates of material loss with use duration, appear in the highest rankings after 400 and 800 strokes respectively and also represent compromises in features. In the case of VSHL, the low relief-angle used is compensated for by the exceptional performance levels of convex/straight plan profile combinations. For VVHH the slightly poorer performance of convex profiles, in combination with convex plans, is compensated for by the high productivity of high edge-angle/high relief-angle combinations.

These results indicate that, under experimentally controlled circumstances, it is edge plan which has the greatest effect on declining or increasing mass material loss with use. Straight plans consistently decline in productivity with use, while convex plans increase mass material loss with use. Concave plans, generally maintain their performance levels (CSHH). That being said, the rate of decline or increase was determined by the degree of compromise provided by additional features such as profile, edge-angle and relief-angle.

Fluctuations in rates of decline and increase in productivity can translate into large differences in the number of strokes required to remove a certain amount of material. Combination VSLL shows substantial increase in material loss over time, such that its selection for use over alternative combinations such as VVHH will result in considerably fewer strokes being required to remove the same amounts of material. The same material loss is predicted to be achieved after 800 strokes using VSLL combinations as is achieved by VVHH combinations after 1200 strokes. Likewise, the choice of either VSLL or CSHH combinations over higher performing VSHH combinations require an extra 400 strokes to achieve at 1200 strokes cumulative material losses equivalent to those achieved by VSHH after 800 strokes.

While marked differences exist in the performance of particular morphological combinations with use duration, a number of clear similarities between the performances of different morphologies are evident within the same use duration. After 100 strokes, differences in material loss between SVHH and VSHH are negligible, so too with SVLL and VSLL. At 400 strokes, combinations SVHH and CSHH remove similar amounts of material, as do SVLL and VSHL. By 800 strokes, CSHH and SVHH are, again, very similar in cumulative material losses, and by 1200 strokes VSLL and CSHH perform to almost identical levels. It is clear that a number of different morphologies are capable of
sustaining the same performance levels by balancing poor performing variables with more advantageous ones.

Table 16 below displays the performance of six artefact morphologies with performance levels positioned in the middle of the range of material losses recorded for scraping artefacts on hard wood. Differences between mass material losses for each duration is again ordinal. The intermediate to low performance levels of these artefacts can be explained by each morphology being a compromise of features.

Table 16. Morphologies of mid-range performers for scraping hard wood (mean cumulative material loss)

<table>
<thead>
<tr>
<th>Position</th>
<th>100 Material Loss (g)</th>
<th>400 Material Loss (g)</th>
<th>800 Material Loss (g)</th>
<th>1200 Material Loss (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>VVHL</td>
<td>1.23</td>
<td>4.33</td>
<td>SVLH</td>
</tr>
<tr>
<td>17</td>
<td>CVHL</td>
<td>1.21</td>
<td>3.99</td>
<td>VCHH</td>
</tr>
<tr>
<td>18</td>
<td>SSHH</td>
<td>1.10</td>
<td>3.61</td>
<td>VVHL</td>
</tr>
<tr>
<td>19</td>
<td>CVHL</td>
<td>1.08</td>
<td>3.55</td>
<td>CVHL</td>
</tr>
<tr>
<td>20</td>
<td>VVHL</td>
<td>1.08</td>
<td>3.54</td>
<td>SSHH</td>
</tr>
<tr>
<td>21</td>
<td>VCHH</td>
<td>0.93</td>
<td>3.19</td>
<td>VCHH</td>
</tr>
</tbody>
</table>

Initials in order indicate plan, profile, edge-angle and relief-angle. Key: S= straight, V= convex, C= concave, H = high, L=low

Table 16 shows that a greater compromise in features exists in the morphologies performing at these lower levels. Combination SVLH, which appears at the top of the 800 and 1200 stroke runs, is the last of the combinations tested involving high performing plans and profiles with the compromise in edge-angle and contact angle responsible for declining material loss with use duration. However, the patterns noted for the higher ranking performers above remain the same. Convex plans continue to increase in mass material loss with use, regardless of the combinations of other features which occur. Likewise, straight plans continue to decline in productivity with use and concave plans fluctuate between the two. The poor combinations of these plans with low performing profiles and edge-angle/relief-angle combinations account for the lower performance levels of each of these morphologies. For example, the generally low performing plan/profile combination of straight/straight is enhanced by a high/high edge-angle/relief-angle combination. However, while the higher performing edge-angle/relief-angle combination serves to increase the performance of straight/straight combinations over the short term, it is unable to override the susceptibility of straight edge plans to declining material loss with use.
The differences between the material loss provided by mid-level performing artefacts during the same duration of use is minimal. In the first 100 strokes, less than 0.2g separate position 16 from position 20. After 400 strokes, the difference is again negligible between the cumulative material losses of positions 17 through to 21. At 800 and 1200 strokes, a difference of less than 1g separate positions 18-21 and 18-20 respectively, despite shifts in the order of morphology performance.

These results indicate that, within a certain range of mid ranked performing artefacts, any number of different morphologies will again be equally capable of performing the same task over a similar length of time. The similarities in performance levels noted between mid ranked artefacts are such that the decision to choose one of these combinations over another will not result in dramatic increases, or decreases, in the number of strokes required to perform the task, such as those noted from amongst the top ranking performers. Performance levels on the whole decrease in accordance with increasing numbers of compromises being made in important artefact features. However, as performance levels decrease, differences in the individual performances of artefacts also seem to narrow, with a larger range of morphological variation capable of producing similarly moderate levels of mass material loss. Differences in levels of performance are therefore greater between the highest performing artefacts than between those removing lower quantities of material when scraping hard wood.

Table 17 below outlines the cumulative material loss of the six lowest performing edge morphologies for scraping hard wood. Each of these morphologies is a combination of the lowest performing features. Common to all six is concave profiles, the poor performance of which is difficult to offset, even when combined with high performing edge-angle and relief-angle combinations. For example, the low/low edge-angle/relief-angle combination occurring on SCLI could not offset the disadvantages incurred on

<table>
<thead>
<tr>
<th>Position</th>
<th>100</th>
<th>Material Loss (g)</th>
<th>400</th>
<th>Material Loss (g)</th>
<th>800</th>
<th>Material Loss (g)</th>
<th>1200</th>
<th>Material Loss (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>SCLI</td>
<td>0.57</td>
<td>VCLI</td>
<td>1.83</td>
<td>CCLI</td>
<td>2.98</td>
<td>CCLI</td>
<td>4.17</td>
</tr>
<tr>
<td>32</td>
<td>VCLI</td>
<td>0.53</td>
<td>SCLI</td>
<td>1.76</td>
<td>SSLI</td>
<td>2.98</td>
<td>SSLI</td>
<td>3.86</td>
</tr>
<tr>
<td>33</td>
<td>CCLI</td>
<td>0.53</td>
<td>CCLI</td>
<td>1.70</td>
<td>SCLI</td>
<td>2.98</td>
<td>SSLH</td>
<td>3.69</td>
</tr>
<tr>
<td>34</td>
<td>SCI</td>
<td>0.50</td>
<td>SCI</td>
<td>1.56</td>
<td>SCI</td>
<td>2.64</td>
<td>CLI</td>
<td>3.48</td>
</tr>
<tr>
<td>35</td>
<td>CCII</td>
<td>0.44</td>
<td>CCII</td>
<td>1.42</td>
<td>CCII</td>
<td>2.49</td>
<td>SCI</td>
<td>3.42</td>
</tr>
<tr>
<td>36</td>
<td>SCII</td>
<td>0.42</td>
<td>SCII</td>
<td>1.30</td>
<td>SCII</td>
<td>2.20</td>
<td>SCII</td>
<td>2.86</td>
</tr>
</tbody>
</table>

Initials in order indicate plan, profile, edge-angle and relief-angle. Key: S = straight, V = convex, C = concave, H = high, L = Low.
material loss by the extremely low performing plan/profile combination of straight/concave. Combination with a convex plan gave VCLH the ability to increase material loss with use duration and move out of the bottom six rankings after 400 strokes. However, with the low performing combinations of profile, edge-angle and relief-angle, cumulative material losses remained low. These results suggest that plan/profile combinations are the primary determinants of productivity, with edge-angle/relief-angle acting as supporting variables.

Differences between the performances of the lowest performing morphologies is again ordinal at each use duration. There is less than 0.1g differentiation between positions after 100 strokes, 0.5g after 400 strokes and after 800 strokes the difference between all 6 morphologies is less than 0.8g. The differences are slightly greater after 1200 strokes with 1.2g difference between cumulative material losses. As such a knapper could save 400 strokes by utilizing a CCHL combination in favour of an SCLH, reaching the same cumulative material loss after 800 strokes as the latter produces in 1200 strokes.

Combination SCHL is by far the poorest combination of features, and remains the lowest performer at every duration of use. Plan, profile, edge-angle and relief-angle are all ill-suited to one another and represent the poorest option within their own categories.

While differences within each of these groups of performance levels are minimal, differences between them are relatively substantial. For example, in the first 100 strokes, the top performing combination of features VSHH produces a material loss of 2.8g, double that produced by the position 16 combination VVHL, and over six times that produced by the lowest performing combination SSHL. After 1200 strokes, combination SSHL produces a mass material loss that measures less than approximately two-thirds of that produced by VVHL and less than one-third of the cumulative material loss attained by SVHH after only 400 strokes. These results provide strong support for the argument that under experimental conditions, differences in edge morphology equate to real and quantifiable differences in edge performance.

Scraping Soft Wood

The most productive combinations of features at 100, 400, 800 and 1200 strokes on soft woods and associated losses in material mass are detailed in Table 18. As with harder wood, the best possible combination of plan, profile, edge-angle and relief-angle greatly
exceeds the performance levels of all other morphologies, with only ordinal differences occurring between the subsequent five positions.

Table 18. Morphologies of the most productive artefacts for scraping soft wood (mean cumulative material loss)

<table>
<thead>
<tr>
<th>Position</th>
<th>100</th>
<th>Material Loss (g)</th>
<th>400</th>
<th>Material Loss (g)</th>
<th>800</th>
<th>Material Loss (g)</th>
<th>1200</th>
<th>Material Loss (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VSLL</td>
<td>2.97</td>
<td>VSLL</td>
<td>10.89</td>
<td>VSLL</td>
<td>20.17</td>
<td>VSLL</td>
<td>28.64</td>
</tr>
<tr>
<td>2</td>
<td>CSLL</td>
<td>2.69</td>
<td>SVLL</td>
<td>10.02</td>
<td>SVLL</td>
<td>18.29</td>
<td>SVLL</td>
<td>25.54</td>
</tr>
<tr>
<td>3</td>
<td>VCLL</td>
<td>2.33</td>
<td>CSLL</td>
<td>9.26</td>
<td>VCLL</td>
<td>15.44</td>
<td>VVLL</td>
<td>22.43</td>
</tr>
<tr>
<td>4</td>
<td>SVLL</td>
<td>2.30</td>
<td>VCLL</td>
<td>8.36</td>
<td>VVLL</td>
<td>15.40</td>
<td>CSLL</td>
<td>22.01</td>
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<tr>
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<td>VSLH</td>
<td>2.20</td>
<td>VSLH</td>
<td>8.07</td>
<td>CSLL</td>
<td>15.00</td>
<td>VSLH</td>
<td>21.20</td>
</tr>
<tr>
<td>6</td>
<td>CSLH</td>
<td>1.99</td>
<td>SVLL</td>
<td>7.42</td>
<td>VSLH</td>
<td>14.93</td>
<td>VCLL</td>
<td>20.65</td>
</tr>
</tbody>
</table>

Initials in order indicate plan, profile, edge-angle and relief-angle. Key: S = straight, V = convex, C = concave, H = high, L = Low

When working soft wood, it is a low edge-angle, low relief-angle combination that is most productive and unsurprisingly, five out of the top six most productive artefacts utilise this combination. The ability for low/low edge-angle/relief-angle combinations to enhance artefact performance has enabled some compromises in plan/profile combinations, such as VCLL, CSLL and VVLL, to still give some of the highest performances and without too greater differences in cumulative material losses. The convex plan offset the poor effects of concave profiles in combination VCLL while the straight profile in combination CSLL offset the poor effects of concave plans. The compromise in profile provided by VVLL was such that it progressed into highest the six positions only after 800 strokes.

Compromises in edge-angle and relief-angle such as VSLH, SVLH and CSLH are offset by combination with the highest performing profile for each of these plans. However, with the exception of VSLH which represents the best plan/profile combination, the ability of profiles to offset the poor performance of plans is limited to the extent that morphologies are able to perform well, but not maintain, highest rates of material loss for every use duration. Combinations CSLH and SVLH disappear from the highest rankings after 100 and 400 strokes respectively. The patterns of increasing and declining productivity with use with edge plan detected for scraping harder wood are not apparent from the results of scraping softer wood. Instead, it appears that each variable, or interaction between variables, contributes relatively evenly to the performance levels of different morphologies.

Fluctuation in rates of material loss with use duration and in the positions of each morphology within the top six performers are evident. However, it must be remembered that the differences exhibited here between the performances of different morphologies are
relevant only to the experimental program and may not be sufficient to be recognized by a
tool user in ‘real life’ situations. The important point here is that differences, however
small, do exist between the performance abilities of different morphologies. At 100
strokes, less than 1g separates all six of the highest performers. However, after 400 strokes
differences in cumulative material loss become greater and result in larger separations
between morphologies. Differences between VSLL and SVLL at 400 strokes measure less
than 0.9g, while those between VCLL and VCLH are less than 0.4g. The difference
between the highest and lowest ranked of Table 17 after 400 strokes however, is over 3g
indicating that even over short term use, the choice to use either of the top two ranked
performers will incur greater advantage on the knapper by reducing the number of strokes
required to complete a task. These differences between the top two performers and the
remaining high ranked morphologies is amplified after 800 strokes and again after 1200
strokes resulting in a difference in cumulative material loss of between 3g and 8g. By
comparison, differences between the performances of morphologies between third and
sixth position remain minimal, measuring less than 1g after 800 strokes and 1.5g after 1200
strokes. The advantages incurred by utilising either of the two highest performing
morphologies is up to 400 strokes in some cases, with a VCLL combination requiring 1200
strokes to reach similar levels of material loss as that provided by VSLL after 800 strokes.

Mid range performing combinations of features used to scrape softer wood are outlined in
Table 19. Each of these combinations again represent compromises in features, with the
effect on performance level directly related to the amount of compromise in morphology
each artefact represented. Few of the morphologies represented in the first 100 strokes
remain within the same six positions throughout the experimental run and differences
between the performance levels of these six morphologies are again ordinal. Despite 11
different combinations of features appearing in the six mid-range positions detailed in
Table 18, differences in the performances of each are extremely low. After 100 strokes,
less than 0.8g difference exists, followed by 1g difference at 400 strokes, 0.9g at 800 strokes
and 1.5g at 1200 strokes. These figures suggest that a wide range of morphologies are
capable of producing similarly moderate levels of material loss over similar periods of time.

Analysis of the lowest performing morphologies for scraping softer wood are detailed in
Table 20. The slight advantage identified for concave profiles on softer wood means that,
in contrast to the dominance of concave profiles in the lowest performing morphologies
on hard wood, the lowest performers on softer wood are more balanced between the
Table 19. Morphologies of mid-range performers for scraping soft wood (mean cumulative material loss)

<table>
<thead>
<tr>
<th>Position</th>
<th>100 Loss (g)</th>
<th>Material Loss (g)</th>
<th>400 Loss (g)</th>
<th>Material Loss (g)</th>
<th>800 Loss (g)</th>
<th>Material Loss (g)</th>
<th>1200 Loss (g)</th>
<th>Material Loss (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>VCCHH</td>
<td>1.30</td>
<td>CVCHH</td>
<td>5.19</td>
<td>VCCHH</td>
<td>8.65</td>
<td>CVCHH</td>
<td>12.33</td>
</tr>
<tr>
<td>17</td>
<td>SVLLH</td>
<td>1.29</td>
<td>CCHLH</td>
<td>4.8</td>
<td>CVCHH</td>
<td>8.63</td>
<td>CVCHH</td>
<td>12.29</td>
</tr>
<tr>
<td>18</td>
<td>CVLLL</td>
<td>1.28</td>
<td>VCHHI</td>
<td>4.68</td>
<td>SVHLL</td>
<td>8.41</td>
<td>VHCH1</td>
<td>12.06</td>
</tr>
<tr>
<td>19</td>
<td>SSSLL</td>
<td>1.20</td>
<td>SCHLL</td>
<td>4.41</td>
<td>CVLLH</td>
<td>8.17</td>
<td>VCHH</td>
<td>11.74</td>
</tr>
<tr>
<td>20</td>
<td>VSHEL</td>
<td>1.14</td>
<td>CVLHH</td>
<td>4.31</td>
<td>CCLLH</td>
<td>7.77</td>
<td>VSHEL</td>
<td>11.01</td>
</tr>
<tr>
<td>21</td>
<td>VVLH</td>
<td>1.09</td>
<td>VSHL</td>
<td>4.19</td>
<td>VSHL</td>
<td>7.75</td>
<td>CCLLH</td>
<td>10.89</td>
</tr>
</tbody>
</table>

Initials in order indicate plan, profile, edge-angle and relief-angle. Key: S= straight, V= convex, C= concave, H= high, L=low

combinations of features. Combinations of all three plans and all three profiles are evident, as well as high/high and high/low edge-angle/relief-angle combinations. Low/high edge-angle/relief-angle mixes perform better than high/low alternatives, explaining the dominance of the latter combinations amongst the lowest ranking morphologies. Again morphologically dissimilar functional equivalents are suggested.

The poor productivity levels of straight/straight plan/profile combinations are also evidenced by the frequency of this combination in the lowest productivity ranks. Regardless of which edge-angle and relief-angle they were combined with in the experimental run, with the singular exception of low/low combinations, straight/straight plan/profiles remained poor performers. This finding is in direct opposition to general observations and attempts by wear analysts to conduct experiments using straight edges and will be discussed in more detail in a later chapter.

Table 20. Morphologies of lowest performers for scraping soft wood (mean cumulative material loss)

<table>
<thead>
<tr>
<th>Position</th>
<th>100 Loss (g)</th>
<th>Material Loss (g)</th>
<th>400 Loss (g)</th>
<th>Material Loss (g)</th>
<th>800 Loss (g)</th>
<th>Material Loss (g)</th>
<th>1200 Loss (g)</th>
<th>Material Loss (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>CVLH</td>
<td>0.72</td>
<td>VVHL</td>
<td>2.73</td>
<td>SSIH</td>
<td>4.59</td>
<td>CVLH</td>
<td>6.38</td>
</tr>
<tr>
<td>32</td>
<td>SSSI</td>
<td>0.70</td>
<td>CCLI</td>
<td>2.50</td>
<td>CVLH</td>
<td>4.24</td>
<td>SSSI</td>
<td>6.26</td>
</tr>
<tr>
<td>33</td>
<td>SSSH</td>
<td>0.67</td>
<td>SCHL</td>
<td>2.29</td>
<td>CCLI</td>
<td>4.03</td>
<td>SSSH</td>
<td>5.65</td>
</tr>
<tr>
<td>34</td>
<td>VVHL</td>
<td>0.57</td>
<td>CVHI</td>
<td>2.24</td>
<td>SSLLH</td>
<td>3.56</td>
<td>VVHL</td>
<td>4.73</td>
</tr>
<tr>
<td>35</td>
<td>CVHL</td>
<td>0.49</td>
<td>SSSH</td>
<td>2.23</td>
<td>SSSI</td>
<td>3.48</td>
<td>CVHL</td>
<td>4.64</td>
</tr>
<tr>
<td>36</td>
<td>SSIH</td>
<td>0.46</td>
<td>SSSLH</td>
<td>1.53</td>
<td>SSSI</td>
<td>2.38</td>
<td>SSIH</td>
<td>3.25</td>
</tr>
</tbody>
</table>

Initials in order indicate plan, profile, edge-angle and relief-angle. Key: S= straight, V= convex, C= concave, H= high, L=low

Differences between cumulative material losses from morphologies at the same use duration are slightly larger for lower ranked morphologies than those noted for top and mid ranked performers. As a consequence, within these lower ranks a number of morphologies are capable of reducing the number of strokes required to complete a task.
For example, differences between material loss at 100, 400, 800 and 1200 strokes are 0.3g, 1.2g, 2.2g and 3g respectively. In the first 100 strokes, differences in performance levels were negligible. After 400 strokes, SSHL alone is producing particularly low levels of material loss with the remaining five morphologies performing to very similar levels. After 800 strokes these differences increase, with SSLH, CVHL and CCHL producing similar cumulative material loss, and SCHL and SSHH producing similar material losses. Both SSHH and SCHL combinations produce higher rates of cumulative material loss after 800 strokes than does SSHL after 1200 strokes. Likewise, combinations SSLH, CVHL and CCHL produce in 800 strokes equivalent material losses to those produced by SSHH and SCHL after 1200 strokes. It was therefore possible in almost all cases of scraping soft wood to enhance even the poorest performing edges in some way or other to increase its utility and decrease the number of strokes required to perform particular tasks.

As with scraping harder wood, differences in the performance of artefacts with morphology are greater between groups of performance levels than within them. That is, within the three groups of six artefacts discussed here from the top, middle and lowest levels of performance identified by experimentation, differences between artefacts tend to be quite small and unlikely to be noticed by a tool user in ‘real life’ situations. However, differences between these general levels of performance are substantially greater. In the first 100 strokes, the highest performing combination VSLL produces a material loss that doubles the amount produced by VCHH positioned number 16 order of performance level, and six times greater than that produced by the lowest performing combination SSHL. After 1200 strokes, combination SSHL achieved similar levels of mass material loss as those achieved by VCHH between 200 and 400 strokes and equivalent to one-nineth of the mass material loss removed by VSLL combinations after 1200 strokes. Again it is apparent that while a number of morphologies may represent morphologically dissimilar functional equivalents, real and quantifiable differences do exist between the performance capabilities of particular edge morphologies.

Sawing

In the previous chapter the following interactions were identified to affect cumulative cut depth in sawing activities over the first 1200 strokes of use:

1. Edge plan and contact material (p=0.042).
2. Edge plan and edge-angle with use duration (p=0.045).
Plan and Contact Material (p=0.042)

All plans are predicted to perform substantially better on relatively softer wood than on hard, while concave plans perform best on harder woods, both convex and concave plans are equally productive on softer wood. The decision to utilise a straight edge on soft wood, or either a convex or straight plan on hard wood, will inevitably have consequences for knapper in the form of performance compromise.

Straight edges produce a log(cumulative cut depth) that is approximately 0.26mm less than that predicted for either concave or convex edge plans at any use duration. If we refer back to Figure 70 from the Chapter 8 (pg 200) plotting log(cumulative cut depth) relative to edge plan, it is possible to translate a cut depth loss into differences in performance over time. After 1200 strokes, a straight plan used on soft wood will achieve similar rates of log(cumulative cut depth) as that achieved by a convex edge plan after only 480 strokes. A cost of more than twice the number of strokes required using a convex edge may be incurred by the use of a straight plan on softer wood. The poor performance of straight plans, coupled with the low survival rates for these plans in sawing activities noted in the previous chapter, means the costs associated with using straight edge plans become even higher.

On harder wood, convex and straight plans are predicted to produce a log(cumulative cut depth) approximately 0.17mm less than that produced by convex plans at any use duration. Again referring back to Figure 70 (pg 200) we can see that convex and straight edges will produce similar log(cumulative cut depths) after 600 and 1200 strokes as could be achieved using a concave plan after approximately 320 and 780 strokes respectively. Again lower survival rates for convex plans, and even lower for straight plans, compound the effects of poorer performance levels, enhancing the costs of choosing either of these plans in preference to a concave plan. These results suggest that, as in scraping activities, even subtle differences between the performance levels of alternative morphologies have the potential to equate to quite substantial differences in the number of strokes required to complete a task.

While a difference of less than 2mm cumulative cut depth may not be noticed by tool users in real life situations, a difference of several hundred strokes in producing the same cut depth as was possible with another morphology might. It is not the depths of cumulative cuts produced by mechanized and controlled experimentation that are relevant to these discussions, but rather the fact that differences are observable and have possible
implications for understanding prehistoric tool using behaviours. The observation that differences exist under experimental conditions lends support to the idea that differences of a dissimilar order or magnitude may also exist between forms used in real life situations, and are worthy of further study.

**Plan and Edge-angle with Duration (p=0.045)**

In the two-way interaction with duration edge-angle is predicted to have no effect on the performance of concave plans, but the performance of convex and straight plans is significantly greater when combined with a low edge-angle and increases with use duration. It was therefore possible to enhance the performance of both convex and straight edge plans by combining them with a low edge-angle, regardless of the hardness of wood worked. In addition, the combination of any plan with a low edge-angle substantially enhances its survival rate. This is also the case for concave plans which perform to equal levels with both edge-angles but have a greater chance of survival when combined with a low edge-angle.

Figure 71 (see pg 201) plots the predicted log(cumulative cut depths) provided by each edge plan with both high and low edge-angles. From this it is clear that log(cumulative cut depth) for both convex and straight edge plans using low edge-angles far exceed those achieved using high edge-angles.

For convex plans, log(cumulative cut depth) averages a 0.3mm difference between high and low edge-angles. This difference equates to 400 strokes with low edge-angles achieving in 600 strokes log(cumulative cut depths) equivalent to those achieved using a low edge-angle after 200 strokes. As this difference between performances increases with duration, after 1200 strokes high edge-angles are predicted to attain log(cumulative cut depth) levels equal to those produced with a low edge-angle after slightly less than 400 strokes.

For straight plans, the difference in the performance of high and low edge-angles is not so large, but follows a similar pattern as that identified for convex plans. Statistically significant differences between the two edge-angles occurs from 400 strokes onwards, with an average difference in log(cumulative cut depth) of 0.16mm. After 600 strokes, high edge-angles are predicted to sustain log(cumulative cut depths) equal to those produced on low edge-angles after 330 strokes. Increasing with use duration, this difference extends to 500 strokes with high edge-angles sustaining at 1200 strokes equivalent log(cumulative cut depths) as low edge-angles after 700 strokes. These results suggest that the need to use a
lower performing combination of features over higher performing alternatives may result in a substantial increase in the number of strokes required to complete the task.

Summary

These results support the two important aspects of tool use outlined above for scraping activities. The first is that if circumstances dictate the need to utilize lower performing qualities of any significant variable, for example a straight edge plan rather than a concave edge plan, these compromises in form may come at a heavy price to the tool-user in terms of the number of strokes required to complete a task. The extent to which these costs might be considered problematic or prohibitive are again dependent upon circumstance and upon which variables (in the case of sawing: plan and edge-angle) have to be compromised. These costs also become greater over time when the relevant variables interact with duration.

The second point is that again, relatively poor performing features may be enhanced and associated costs minimized by combining them with other higher performing features. By altering the levels of different relevant variables it is possible to enhance both the performance levels of the edge and its longevity. These results, coupled with the ability to utilize any shaped longitudinal profile in sawing activities without compromising on performance means that as with scraping, a number of different combinations of morphological features are capable of producing similar cumulative cut depths from sawing wood.

Combined Effects

As with scraping, the nature of these data makes them ill-suited to performing general statistical analyses of the combined effects of all the significant variables affecting artefact performance. Comparisons between the combined effects of significant variables on performance are achieved in the following discussion by exploring the relative rankings of different combinations of variables by performance level. The combined effects of each morphology on cumulative cut depth in sawing are discussed separately for each wood hardness.
Sawing Hard Wood

The small number of effects and interactions between variables identified as affecting cumulative cut depth in sawing activities limits the number of compromises and trade-offs possible. This means that many different morphologies exist that perform at equal levels.

Table 21 below ranks the average performance of each combination of variables experimentally identified as having a statistically significant effect on sawing hard wood. The minimal number of variables identified to affect cumulative cut depth makes it possible to summarise the performances of the entire sawing experimental program for hard wood in the one table. From this table the only trade-offs available to knappers are clear. Being the most suitable edge plan for sawing hard wood, concave plans attain highest cumulative cut depths and are positioned in the top two combinations for sawing hard wood. Edge-angle does not affect the overall performance of concave edge plans. The poor performance of convex plans on hard wood is offset by combination with a low edge-angle and makes it the third highest performing combination. Despite their combination with a low edge-angle, straight plans perform at a slightly lower level than the previous three combinations, followed by the poorest plan/edge-angle combinations of SH and LH. These results highlight the same ability identified for scraping activities to enhance poorly performing edge plans by combining them with higher performing levels of variables - in this case a low edge-angle.

Table 21. Morphology performance for significant variables in sawing hard wood (mean cumulative cut depth)

<table>
<thead>
<tr>
<th>Position</th>
<th>100 Cumulative cut (mm)</th>
<th>400 Cumulative cut (mm)</th>
<th>800 Cumulative cut (mm)</th>
<th>1200 Cumulative cut (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CH 0.56</td>
<td>CH 1.44</td>
<td>CH 2.06</td>
<td>CL 2.74</td>
</tr>
<tr>
<td>2</td>
<td>CL 0.52</td>
<td>CL 1.36</td>
<td>CL 2.052</td>
<td>CL 2.63</td>
</tr>
<tr>
<td>3</td>
<td>SL 0.50</td>
<td>SL 1.34</td>
<td>SL 2.03</td>
<td>SL 2.62</td>
</tr>
<tr>
<td>4</td>
<td>SH 0.36</td>
<td>SH 1.19</td>
<td>SH 1.80</td>
<td>SH 2.38</td>
</tr>
<tr>
<td>5</td>
<td>LH 0.34</td>
<td>LH 0.86</td>
<td>LH 1.31</td>
<td>LH 1.69</td>
</tr>
<tr>
<td>6</td>
<td>VH 0.22</td>
<td>VH 0.67</td>
<td>VH 0.99</td>
<td>VH 1.32</td>
</tr>
</tbody>
</table>

Initials in order indicate plan and edge-angle. Key S=straight, V=convex, C=concave, H = high, L=Low

The performances of plan and edge-angle combinations in sawing shows a clustering of the performances of concave plans and convex/low combinations throughout the 1200 stroke run (see Figure 72). By comparison, the differences between the performances of straight/low, straight/high and convex/high combinations increase with use duration. In the first 100 strokes, the highest performing combinations of concave/high and concave/low attain cumulative cut depths that are more than double those attained by
Compromises and Trade-Offs

convex/high combinations. The effect of duration in this case comprised a similar rate of cumulative cut depth for each morphological combination. After 1200 strokes, concave/high and concave/low combinations continue to produce cumulative cut depths that double those produced by convex/high combinations. The ability for certain combinations to produce twice the material loss of others over the same period of time or, conversely, to require double the number of strokes to produce similar levels of cumulative cut depths, indicates that differences exist in the performance levels of different morphological combinations. However, the clustering of performance levels evident between concave plans and convex/low combinations indicates that a number of morphologically dissimilar forms are able to perform as functional equivalents in sawing activities, as they could in scraping activities. While concave/high, concave/low and convex/low combinations are found to perform to similarly high levels when sawing hard wood is important to note that the combination of any plan with a low edge-angle increases its probability of survival. As such, the use of concave/high combinations, rather than the concave/low alternatives which utilize low edge-angles as well as high performance levels, may come at a cost of longevity of artefact function to the tool-user.

![Figure 72. Changing effects of plan and edge-angle combinations on cumulative cut depth when sawing hard wood. Initials in order indicate plan and edge-angle. Key S=straight, V=convex, C=concave, H=high, L=low](image)

The number of morphologically dissimilar functional equivalents existing for sawing activities exceeds those noted for scraping activities, due to changes in longitudinal profiles being found not to have a statistically significant effect on performance. This means that profiles can be added to each of these combinations without affecting artefact performance. The different combinations of morphological features found,
experimentally, to perform to the same level are outlined in Table 22. These results illustrate the wide range of morphological combinations capable of performing sawing activities to equally high performance levels.

Table 22. Morphologically dissimilar functional equivalents for sawing hard wood.

<table>
<thead>
<tr>
<th>Morphological Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCH</td>
</tr>
<tr>
<td>CVH</td>
</tr>
<tr>
<td>CSH</td>
</tr>
<tr>
<td>CCL</td>
</tr>
<tr>
<td>CVL</td>
</tr>
<tr>
<td>CSH</td>
</tr>
<tr>
<td>VCL</td>
</tr>
<tr>
<td>VVL</td>
</tr>
<tr>
<td>VSL</td>
</tr>
<tr>
<td>SCL</td>
</tr>
<tr>
<td>SVL</td>
</tr>
<tr>
<td>SSL</td>
</tr>
<tr>
<td>VCH</td>
</tr>
<tr>
<td>VVH</td>
</tr>
<tr>
<td>VSH</td>
</tr>
<tr>
<td>SCH</td>
</tr>
<tr>
<td>SVH</td>
</tr>
<tr>
<td>SSH</td>
</tr>
</tbody>
</table>

Combinations of the same colour are functional equivalents, and coloured groups are ordered by highest through to the lowest performers. Initials in order indicate plan, profile and edge-angle. C = concave, V = convex, S = straight, H = high, L = low.

Sawing Soft Wood

The average performance and rank of the significant variables affecting cumulative cut depth when sawing soft wood is outlined in Table 23. As with sawing hard wood, the effects and interactions between all relevant variables affecting the sawing of soft wood can be reduced to a single table.

The advantage of convex and concave plans for working soft woods and the ability for low edge-angles to further enhance convex plans is evident, with convex/low combinations consistently the best performers at each use duration. The poor performance of straight edge plans on soft wood is slightly offset by combination with a low edge-angle; however both straight plans remain least productive. As with sawing harder wood, concave plans perform equally well, regardless of the edge-angle with which they are combined. However, in contrast to sawing harder wood, convex/low combinations are consistently the highest
performers, with concave plans clustering at slightly lower productivity levels throughout the experimental run (see Figure 73).

Table 23. Morphology performance for significant variables in sawing soft wood (mean cumulative cut depth)

<table>
<thead>
<tr>
<th>Position</th>
<th>100 Cumulative cut depth (mm)</th>
<th>400 Cumulative cut depth (mm)</th>
<th>800 Cumulative cut depth (mm)</th>
<th>1200 Cumulative cut depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CH 1.93</td>
<td>CH 5.18</td>
<td>CH 7.84</td>
<td>CH 10.13</td>
</tr>
<tr>
<td>2</td>
<td>CL 1.41</td>
<td>CL 3.67</td>
<td>CL 5.22</td>
<td>CL 6.95</td>
</tr>
<tr>
<td>3</td>
<td>V11 1.32</td>
<td>V11 3.45</td>
<td>V11 5.21</td>
<td>V11 6.67</td>
</tr>
<tr>
<td>4</td>
<td>V11 0.87</td>
<td>V11 2.57</td>
<td>V11 3.84</td>
<td>V11 5.08</td>
</tr>
<tr>
<td>5</td>
<td>SL 0.71</td>
<td>SL 2.33</td>
<td>SL 3.52</td>
<td>SL 4.65</td>
</tr>
<tr>
<td>6</td>
<td>SH 0.67</td>
<td>SH 1.69</td>
<td>SH 2.58</td>
<td>SH 3.31</td>
</tr>
</tbody>
</table>

Initials in order indicate plan and edge-angle. Key S=straight, V=convex, C=concave, H=high, L=low.

Figure 73 shows the relative advantages of utilizing a convex/low combination over other available alternatives increase with use duration, with rates of increase much higher for convex/low combinations than for alternative morphologies. However, the slightly lower survival rates of convex/low combinations, relative to the slightly lower performance levels but higher probability of survival of concave/low combinations, means that the tool user may be required, in some cases, to accept a compromise between performance and longevity. Either choice may require the sacrifice of one or other of these features in accordance with individual circumstances.

As with sawing on hard wood, the performances of plan and edge-angles tend to cluster slightly, with concave plans performing at similar levels and convex/high and straight/low combinations performing similarly (see Figure 73). This being said, dramatic differences do exist between the performance levels of particular combinations. Less than 1mm separates the performance levels of all six combinations after 100 strokes, however, even in these early stages of use, the highest performing combination of convex/low achieves cumulative cut depths that are almost three times those achieved by the lowest performing combination of straight/low. This difference between highest and lowest performing combinations remains the same over the experimental run. As such, after 1200 strokes, straight/high combinations attain cumulative cut depths equivalent to those attained by convex/low combinations after slightly fewer than 250 strokes. If, however the poor performance of straight plans is coupled with the slightly better performing low edge-angle, these differences are lessened, with some of the costs associated with using a straight edge plan offset by combination with a low edge-angle. When combined with a low edge-angle,
straight plans could achieve, in 1200 strokes, equivalent cumulative cut depths to those achieved by convex/low combinations after 350 strokes. In this case, the enhancement of straight plans by low edge-angles reduce the number of strokes required to reach cumulative cut depths of approximately 4.6mm by 100 strokes. These differences illustrate the existence of dramatic differences in the performance levels of different morphologies, the magnitude of which often increases with use duration.

![Graph showing changing effects of plan and edge-angle combinations on cumulative cut depth when sawing soft wood.](image)

**Figure 73. Changing effects of plan and edge-angle combinations on cumulative cut depth when sawing soft wood.** Initials in order indicate plan and edge-angle. Key S=straight, V=convex, C=concave, H=high, L=low

As with hard wood, the relatively few statistically significant variables affecting cumulative cut depth on soft wood enables a number of different combinations of morphological features to perform as functional equivalents. For each plan/edge-angle combination there are three possible combinations with longitudinal profile which have no effect on the performance levels of individual morphologies. This allows for a large number of morphologically dissimilar functional equivalents to be used in sawing soft wood. Table 24 highlights these equivalencies by grouping functional equivalents for each stroke duration according to colour.

**SUMMARY AND CONCLUSIONS**

The results in this chapter highlight a number of important implications for the interpretation of stone artefacts in behavioural systems. These can be summarized as follows:
Table 24. Morphologically dissimilar functional equivalents according to performance group for sawing soft wood

<table>
<thead>
<tr>
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Combinations of the same colour are functional equivalents, and coloured groups are ordered by highest through to the lowest performers. Initials in order indicate plan, profile and edge-angle. C= concave, V = convex, S=straight, H = high, L = Low

1. The ability of morphological attributes to contribute to artefact performance means that certain combinations of features produce higher levels of cumulative material loss/cut depth or longer use-lives than others. This implies that correlations between form and function can be made in some cases. However, discrepancies between the variables found to enhance performance and those found to impact upon use longevity are such that, in some cases, performance may come at the cost of longevity and vice-versa. As such, the decision to utilize one combination of features over another may vary in accordance with which of these attributes the tool-user values most in each circumstance.

2. Poor performance levels attained by one variable, such as a poor edge plan, can be offset or enhanced by combination with higher performing features of other variables, such as low edge-angles. Where only one variable is compromised in any combination, the use of other high performing features is generally able to compensate, leaving a range of morphologically different forms performing well as functional equivalents. It is possible, in some cases, for quite a lot of compromise in morphology to occur without incurring huge penalties in performance or longevity. These results indicate that quite large ranges of morphological variability are possible without compromising performance levels. As such, direct
correlations between morphology and function in archaeological assemblages may be problematic.

3. In most cases, however, deviations from those combinations of features that achieve highest performance levels in each task, or on each contact material, result in costs/trade-offs. When more than one variable represents a compromise from the highest performing features, the effect on overall performance is greater and associated costs increase. Within the experimental program costs relate to either the number of strokes required to complete a task or, in the case of sawing activities only, to the number of strokes the edge is able to perform (ie longevity) before a new edge needs to be manufactured. In general, the greater the number of high performing variables compromised, the greater the associated costs to the tool-user. These results suggest that, in situations in which the highest performing combinations of features are not available to the tool user, compromises in forms will involve trade-offs in either the number of strokes required to complete the task or the longevity of the artefact itself, or both. As such, depending upon the materials available to him and the circumstances involved, the tool user may again choose to minimize one or other of these costs by choosing a particular combination of features known to enhance one or other of these aspects of tool use.

4. Certain morphological features are almost impossible to compensate for in the experimental system. When scraping soft wood, concave profiles cannot be enhanced to reasonable performance levels, regardless of the combination additional variables. The same can be said of straight/straight plan/profile combinations which, contrary to popular thinking, are one of the poorest combinations possible in both scraping and sawing actions on both hard and soft wood. The contradictory nature of these results, with commonly assumed notions of the relationship between form and function, indicate that current assumptions may be misdirected. The discovery that the most productive combinations of features, under experimental circumstances, differ from those thought to be most suitable for particular tasks suggests that artefact analysts may have overlooked important attributes in previous studies, instead applying a misdirected focus on alternative morphologies.
The previous two chapters have identified similarities and differences in the performance of various morphologies. Different performance levels, survival rates and rates of decline and increase in material loss/cut depth over time have all been explored and their implications for interpretations of artefact function discussed. In the following chapter possible factors contributing to these differences are explored by examining changes to the working edge through scarring with use and the possible impact scarring may have on each of these aspects of artefact performance.
CHAPTER 10

SCARRING AND PERFORMANCE

INTRODUCTION

The previous two chapters identify combinations of morphological and use related variables that dictate artefact performance, rates of decline in productivity with use and the length of time a particular artefact is likely to be used before it is no longer sufficiently productive to justify continued use without retouch or rejuvenation. In this chapter, explanation is sought for why some artefacts are more productive or longer lasting than others.

The process of using an artefact results in the relatively frequent fracturing of stone from the working edge, in the form of either flake scars or abrasion. As a consequence, the use process inflicts a number of changes to the working edge, affecting the area of the edge in contact with material, its edge-angle and relief-angle and its overall shape in both plan and longitudinal profile. An artefact's ability to perform and maintain productivity levels is therefore likely to be affected by changes to the edge from use related scarring. As a result, use scarring has the potential to enhance or hinder artefact effectiveness either by changing the variables known to impact upon productivity or by resharpening the working edge. In this chapter we examine the susceptibility of particular variables to edge scarring and its effect on artefact effectiveness and longevity.

SCARRING AND USE

Scars result in a number of changes to the working edge, depending upon their number and specific properties, including initiation type, size and orientation. Observations made during the experimental process support a number of clear and generally accepted Effects of scarring on the shape and features of the edge being used. The type of initiation, size and frequency of scarring incurred by an edge inevitably affects the extent to which use scarring impacts upon the shape of the working edge, by changing the amount of the working edge in contact with material during use. For example, convex plans or profiles concentrate the force of use to a small area at the apex of the convexity; however the occurrence of scarring at the apex flattens out parts of the convexity and straightens the
working edge. As the edge straightens, the portion in contact with the worked material increases and spreads the applied force over a wider area. Concave plans and profiles tend to be affected in a similar way. When a concave edge is used to scrape a flat surface, the two points of contact are the convexities on either side of the concavity between them. In essence, concave edges concentrate force evenly on these two narrow points. Scarring tends to increase the size of these contact areas by flattening out the apexes and creating larger areas of contact. By comparison, scarring along a straight edge or straight profile may result in a decrease in the amount of edge in contact with the material by taking away areas of the working edge.

The amount of stone removed from the artefact edge can also be observed to differ according to the type of initiation responsible for the removal of each flake. While the size of the scars is obviously an important factor, bending and hertzian initiations remove different amounts of material from the working edge. A bending initiated scar will, in general, remove a greater amount of the working edge than will a hertzian initiated scar of the same size. As such, the frequency of each type of initiation will have differing effects on edge morphology.

In most cases, scarring produced through use increases the angle of the working edge at that point along the edge, while low edge-angles gradually becoming higher through continued scarring. This change is less pronounced on edges angles that are already high. In some cases, such as where scarring events overlap with previous scars, or where scarring emanates from both aspects of the working edge at the same point, scarring can enable the angle to be maintained or, in some cases, slightly reduced. However, while this is regularly seen on bifacially retouched flakes where a concerted effort has been made to maintain edge-angle, it is rare for use scarring to occur on both aspects of the same point on the edge with enough regularity in features to enable a similar effect.

In activities where only one aspect of the working edge is in contact with the material, such as scraping/planning motions, the orientation of the scar affects the relief-angle used. In the experiments used in this thesis, the contact surface is always the ventral surface in scraping activities. In this case, scars that emanate from the ventral to dorsal surface simply increase the edge-angle being worked. However, those emanating from the dorsal to ventral surface increase the edge-angle being used, as well as the angle between the contact surface and the material.
Use Scarring and Edge Performance

The first analysis investigates whether a direct relationship exists between use scarring and effectiveness. To examine whether the incidence/absence of scarring events within individual 200 stroke intervals affects material loss, the material loss within each interval is examined, rather than cumulative material loss over the duration of the experiment. As scarring events are recorded at the end of each use interval, it is unclear how many strokes of each interval occur before or after each scarring event. Where scars occurred early on the use interval, the immediate effects of the scar on material loss would be evident in that interval. However, where scarring occurs at the end of an interval, the effects of the event may not become clear in mass material loss measurements until the following use interval. As such, statistical analyses are conducted measuring material loss or cut depth in both the same interval as a scarring event and the interval immediately following an event.

Relationships between scarring and material loss/cut depth in the same interval are found to be stronger than relationships between scarring and effectiveness in the next interval. As such, the results of statistical analyses described here use material loss/cut depth in a 200 stroke interval and the incidence/absence of scarring in that same interval to explore relationships between scarring and edge performance.

The data is longitudinal as measurements are taken on each artefact every 200 strokes. Therefore a linear mixed model was fitted to the data, using log material loss as the response variable. Interval (as a factor), occurrence/absence of scarring and their interaction were fitted as fixed effects, with artefact as a random effect. Non-significant terms were removed from the model. This model examines whether effectiveness changes from interval to interval during the experiment, whether occurrence/absence of scarring affects effectiveness, and whether any effect is different in different intervals.

For scraping, the analysis identified the following 3 important effects:

1. There are significant differences between the material losses in different intervals (p<0.001).
2. The occurrence of scarring events significantly increases artefact effectiveness (p=0.018) and
3. the increase is consistent across intervals (interaction not significant).
For sawing, statistical analysis showed that there are significant differences in cut depth in different intervals (p<0.001).

Figure 74 shows the predicted change in material loss over time both with and without edge scarring, in scraping activities. This figure illustrates a number of important points relating edge scarring to artefact performance. The first is that the amount of material that an artefact is able to remove in 200 strokes generally declines with usage. The second is that the occurrence of scarring increases the amount of material the artefact is able to remove during that use interval. At all stages in the experimental run, more mass was removed by edges, with scars being produced along the working edge. These results indicate that scarring has a positive effect on mass material loss and, in so doing, potentially increasing the number of strokes able to be performed before rejuvenation of the edge is necessary.

QUALITY OR QUANTITY

Having discovered a relationship between scarring and effectiveness, it became necessary to determine whether it was the number of scars or the types of scars that were most important in enhancing artefact performance. Given the ability of scarring to change the nature of the working edge, and the fact that scarring events increased the amount of material lost in each interval, it seemed possible that the natures of the scars themselves, as well as their frequency, were contributing factors.
Scar Quantity

Statistical analyses were designed to establish whether the number of scars incurred by the edge in an interval resulted in proportionately greater artefact productivity in that interval. These analyses involved fitting linear mixed models to the data, using the number of scars as the explanatory variable (as a linear term), the artefact number as a random effect and the log10(material loss) or log10(cut depth) as the response variables for scraping and sawing respectively.

The range of scars incurred in any one interval was between 1 and 9 scars in scraping activities and 1 and 6 scars in sawing activities. The rarity of scars occurring in the higher numbers of those ranges in each activity meant that for comparative purposes, only those intervals incurring between 1 and 6 scars in scraping activities and 1 and 4 scars in sawing activities gave enough data to perform the analyses. The log (material loss) and log (cut depth) were used as the response variable for each interval.

Table 25. Linear equations for the effect of specific scar numbers on log(material loss) and log(cut depth)

<table>
<thead>
<tr>
<th>Action</th>
<th>Model for scar number</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scraping</td>
<td>P=0.004</td>
<td>Log10(material loss) = 0.167 + 0.03674*scar number</td>
</tr>
<tr>
<td>Sawing</td>
<td>P=0.002</td>
<td>Log10(cut depth) = -0.436 + 0.1144*scar number</td>
</tr>
</tbody>
</table>

![Figure 75. Predicted effect of scar number on material loss for Scraping activities.](image-url)
Removing scar features from the equation and looking solely at the frequency of scars incurred and the resultant material loss or cut depth per interval revealed a highly significant effect of scar frequency on material loss and cut depth respectively. Table 25 above outlines the effect of additional scars on artefact performance for each activity as an equation fitted to a linear model. In scraping activities, each additional scar increases the log(material loss (g)) for every 200 strokes by approximately 0.04g. In sawing activities, an increase of approximately 0.11mm occurs in log(cut depth mm) for each additional scar incurred.

These equations are graphed above and below, with Figure 75 referring to scraping activities and Figure 76 referring to sawing. In each case it is clear that the occurrence of scarring in any interval increases material loss and cut depth and that, in each case, the greater the number of scars the greater the material loss or depth of cut generated.

![Graph showing predicted effect of scar number on material loss for Sawing activities](image)

**Figure 76. Predicted effect of scar number on material loss for Sawing activities**

Under experimental conditions therefore, the occurrence of scarring increases the performance of the working edge, with increases in performance corresponding to increases in the number of scars incurred by the edge in any one interval. The more scars incurred the greater the enhancement of that edge's performance within the use interval.

**Scarring and Artefact Use-life**

Given that material loss or cut depth increases in relation to the number of scars incurred by the working edge, it is predicted that scarring also prolongs use-life, that is, it extends the length of time for which the artefact continues to be considered useful. In order to test
this prediction, another statistical analysis was conducted and designed to answer the questions does scarring extend the use life of an artefact and if so, how much does each scar contribute to the working life of the edge? Using the arbitrarily defined point of discard outlined in Chapter 6 (failure to produce 0.5g material loss or 0.5mm cut depth for each of three successive runs of 200 strokes), the total number of scars accumulated by each artefact at the point of discard and the maximum duration of use (discard point), the maximum duration was regressed on the total number of scars.

The analysis found that scarring has a significant effect on the length of time an artefact may be considered useful (p<0.001) increasing the usability-life of an artefact by an average of 35 strokes per scar. This relationship is expressed in the equation below and represented in Figure 77:

\[ \text{Duration} = 1727.5 + 35.09 \times \text{scar} \]

Scarring was also found to enhance the longevity of artefacts used in sawing activities (p=0.0298) extending the edges use-life by an average of 49 strokes per scar incurred. This relationship is expressed in the equation below and represented in Figure 4.

\[ \text{Duration} = 1066.2 + 49.37 \times \text{scar} \]

![Figure 77. Rate of extension of artefact use-life per scar incurred in Scraping and Sawing](image)

These results indicate a circular causal process whereby the more scars an edge incurs, the longer it will meet performance requirements which, in turn, results in greater scar numbers and so on. While these conditions have obvious constraints and cannot continue in this
fashion forever, it is predicted that edges that have a higher susceptibility to scarring will be advantageous in terms of the long term useability of the artefact. In order to test this idea, it is necessary to explore the relationship between scarring frequency and edge morphology.

Scarring and Morphology

In order to determine which attributes of an artefact and its use were most responsible for scar frequency a statistical analysis was conducted to answer the question is scarring the product of use (relief-angle, contact material), morphology (edge plan, profile and angle) or length of use (number of strokes performed) or a combination of these aspects of artefact use? Three Poisson generalized linear models were fitted, each having number of scars as the response variable and one of the three groups of variables as explanatory terms. The change in deviance for each relative to a null model (in which no explanatory variables occur) and associated p-value are compared in Table 26 below, relating to scraping activities.

Table 26. Effect of various aspects of artefact use on generation of edge scarring in Scraping activities

<table>
<thead>
<tr>
<th>Terms</th>
<th>Deviance</th>
<th>df</th>
<th>Change in df</th>
<th>Significance Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morphology</td>
<td>272.66</td>
<td>58</td>
<td>160.55</td>
<td>0.004</td>
</tr>
<tr>
<td>Usage</td>
<td>420.93</td>
<td>68</td>
<td>12.28</td>
<td>0.580</td>
</tr>
<tr>
<td>Longevity</td>
<td>337.46</td>
<td>70</td>
<td>95.75</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

The table shows that length of use (p<0.001) has the most effect on scar frequency, followed by morphology (p=0.004) which includes edge plan, profile and angle. Usage variables, including contact material and relief-angle do not have a significant effect on scar frequency.

In sawing activities, the effect of each of these variables is slightly different. Neither morphology nor usage variables are found to effect frequency of edge scarring, with length of use found to be the only important contributor (p=0.039).

While usage variables were not found to affect scar frequency on their own, it was considered possible that interactions exist between usage and morphology that contribute to scar frequency. As such, a second Poisson GLM was fitted to the data in which plan,
longitudinal profile, edge-angle, relief-angle, and contact material and all two way interactions were compared with cumulative scar number as the response variable.

For scraping activities, the analysis identified significant interactions between edge-angle and relief-angle (p=0.024) and plan and longitudinal profile (p=0.045), with each contributing to the frequency of edge scarring. The interaction between edge-angle and relief-angle is graphed in Figure 78 below. This figure and subsequent figures 79, 80, 81 and 82 plot mean scar frequencies relative to various morphological and use variables. Lines have been drawn connecting the same variables in these figures in order to clarify connections between relevant variables. They do not indicate that intermediate measures exist between markers.

Figure 78 shows that where relief-angle is high, there is no effect on edge-angle. However, where relief-angle is low, a low edge-angle will result in approximately three times the number of scars than those incurred by high edge-angles. These results indicate that a significant cause of scarring frequency may be the product of variables that are entirely unknown to the analyst when presented with an archaeological specimen; that is, the angle at which the artefact was used. This means that before the analyst can attempt to identify function they must first consider the effects of the observable features of plan, profile and edge-angle, as well as unobservable features such as relief-angle, before the effects of contact material or the action involved may be included.

![Figure 78. The interaction between edge-angle and relief-angle on frequency of edge scarring in scraping actions](image-url)
The interaction between edge plan and longitudinal profile is illustrated in Figure 79 and shows that concave plans incur the greatest numbers of scars when combined with convex profiles, and convex and straight plans incur most scars when combined with straight profiles. Lowest scar frequencies occur when concave plans are combined with concave profiles, and convex and straight plans are combined with convex profiles. These results indicate that, under controlled circumstances, certain combinations of features are more susceptible to use scarring than others. Given this ability for scarring to contribute to both the performance and use-life of an artefact it seemed plausible that the highest performing and longest lasting artefact combinations were also those that scar the most.

The discussion of artefact performance in Chapter 8 showed that, during scraping activities, the most productive edge-angle/relief-angle combination was indeed low/low while low edge-angles were found to last longer than high edge-angles. These results, combined with the identification that low/low combinations also scar most frequently, lend support to the ability of frequent scarring to prolong use life and enhance performance. The interaction between edge plan and longitudinal profile identified in Chapter 8 indicated convex/straight, concave/straight and straight/convex as the most productive forms. These results conflict with those found for edge scarring frequency detailed in Figure 79.

![Figure 79. The interaction between edge plan and longitudinal profile on frequency of edge scarring in scraping actions](image)

While convex/straight combinations consistently perform at the highest levels and scar most frequently, concave and straight plans scar more frequently when combined with
lower performing profiles. These results indicate that, while scarring is beneficial to performance and artefact longevity, susceptibility to scarring will not be sufficient to counteract the effects of poor morphological combinations. Morphological combinations of features that enhance edge performance and use-life are therefore more important than features that enhance susceptibility to scarring.

In sawing activities, edge-angle ($p<0.001$) and contact material ($p=0.039$) each were found to have an effect on scar frequency. The effects of these variables are illustrated in Figure 80.

![Figure 80. Effects of edge-angle and contact material on frequency of edge scarring](image)

Low edge-angles incurred greater scar frequencies than high edge-angles, regardless of contact material, with soft wood consistently generating greater scar numbers than hard wood. Each of these effects is consistent with those identified in Chapter 8 in which greater cut depths occurred when sawing soft wood or using a low edge-angle than when sawing hard wood or using and high edge-angle. In the case of sawing, variable susceptibility to edge scarring corresponds with its ability to enhance effectiveness and longevity.

In addition to scar quantity, various features of the scars themselves were examined in order to assess their ability to contribute to edge performance. It was thought possible that discrepancies between variables identified to have a significant effect on performance and those that effect susceptibility to edge scarring in scraping activities may be explained by different levels of performance in the features of the scars themselves, rather than frequency alone.
Scar Quality

A second set of statistical analyses was therefore performed to investigate whether any of the scar feature variables - orientation, initiation and size - affected the amount of material lost. Each analysis was performed separately as it used a different subset of the data. Each analysis used only those intervals in which all the scars that occurred exhibited the same features. For example, the scar orientation analysis used only the intervals in which all new scars where orientated either dorsal to ventrally or ventral to dorsally. Scarring events in which several scars were removed, but their orientations differed, were not included in the analysis in order to eliminate any noise in the data caused by mixtures of both initiation types. Similarly, only those intervals in which all new scars incurred had either hertzian or bending initiations, were included in analysis of initiation type. The variation in the features of scars that formed during one use interval mean that many intervals could not be included in the analysis. It is therefore possible that some of the marginally significant effects identified in the analysis of features below would increase in significance, were it possible to draw from a larger number of intervals.

These analyses again used linear mixed models with log(material loss) in analyses of scraping or log(cut depth) in analyses of sawing as response variables, artefact number as a random effect, and scar feature (orientation, initiation and scar size separately), scar number (as a factor) and their interaction as fixed effects.

Significant Features

In scraping experiments, none of the particular scar features tested (initiation, orientation and size) had a significant effect on material loss. This may be due in part to the fact that only use intervals, in which all produced scars had that same feature, were used in the analysis. The large number of intervals in which several differently sized scars occurred were all excluded from the analysis relating scar size to material loss. Likewise, all intervals in which both bending and hertzian initiated scars occurred were excluded from analysis of scar initiation type and material loss and, again, for scar orientation. As such, it is possible that the inability to detect significant effects of scar feature on material loss is the product of an insufficient number of relevant use intervals in each case. The results of analysis of scar orientation and material loss give some indication that this may be the case with a marginally significant effect of scar orientation on material loss (p=0.089). Dorsal to
ventral scars were associated with greater material loss than ventral to dorsal scars. However, the present study was unable to clarify this issue further.

In sawing experiments, orientation did not have a statistically significant effect on cut depth. This is to be expected, given that in sawing activities both aspects are in constant contact with the worked material. Scar initiation showed a marginally significant effect on cut depth (p=0.067) with bending initiations resulting in greater cut depth than hertzian initiations. Scar size, however, had a highly significant effect on cut depth (p=0.0002), with the increase in performance proportionate to the size of the scars removed. Figure 81 details equations of predicted log(cut depths) relative to scar sizes and frequency, and shows that larger scars resulted in greater cut depth, followed by medium, small and tiny.

The discovery that, under controlled circumstances, particular scar features were able to enhance edge performance implies that edges that are more susceptible to these types of features may perform better than those that are not. Correlations between the occurrence of scar features and relevant use and morphological variables have already been discussed in Chapter 7 in relation to the distinctiveness of scar features in wear patterning. As such, these results are revisited only briefly here within the context of edge performance, exploring in greater detail the ability of particular scar features to contribute to edge performance.

In scraping activities, scar orientation was found be affected by relief-angle (p<0.001), edge-angle (p=0.029) and that interactions existed between plane and contact material (p=0.004) and longitudinal profile and contact material (p=0.003). These interactions
indicate that dorsal to ventral scars occur in higher proportions where relief-angles are high and edge-angles are low (Chapter 7, Figures 14 and 15, pgs 132-134). This result differs slightly from performance measures in which edge and relief-angle combinations perform best when combined with the same size angle (Chapter 8, pg 191). They suggest that the slight functional advantages incurred by an edge, through a higher frequency of dorsal to ventral orientated scars with high relief-angles, was not sufficient to compensate for the poor performance of high relief-angles with low edge-angles.

The interaction between longitudinal profile and contact material shows that all profiles are equally susceptible to dorsal to ventral orientated scars on hard wood while, on soft wood, straight and concave profiles experience higher proportions of this orientation (Chapter 7, Figure 16, pg 34-35). This relationship is counter to that identified for performance with profiles found to perform equally well on soft wood (Chapter 8, pg 193-194). As such, the advantages of higher incidences of dorsal to ventral orientated scars by concave and straight profiles on soft wood were insufficient to impact greatly on performance.

On the basis of these results it seems that while a higher susceptibility to scar features identified to increase edge performance will be advantageous to the working edge used in scraping activities, it may not be sufficient to override the more dominant effects of morphological and use related variables on performance.

In sawing activities, frequency of bending initiations was found to be affected by three interactions; plan with longitudinal profile (p<0.001), plan with edge-angle (p=0.023) and plan with contact material (p=0.028) (Chapter 7, pg 143).

The interaction between plan and edge-angle showed straight plans resulted in substantially greater proportions of bending initiations when combined with a low edge-angle than with a high. Bending initiations were more common on low edge-angles than on high, with the exception of concave plans which experience very low levels of bending initiations, regardless of edge-angle (Chapter 7 pg 144). These results suggest that the susceptibility of convex plans to bending initiations was likely to have assisted in achieving such high performance levels. However, the high performance of concave plans, despite experiencing low frequencies of bending initiations, and poor performance of straight plans despite high frequencies of bending initiations (Chapter 8 pg 200-201), suggests that the effects of bending initiations on performance are not sufficient to counter the effects of stronger morphological and use related variables.
Scar sizes were also found to affect edge performance in sawing activities with increasing scar sizes accompanied by corresponding increases in effectiveness. Interactions existed between every variable in affecting an edges susceptibility to scars of various sizes. These interactions were longitudinal profile and contact material \((p<0.001)\), plan and longitudinal profile \((p<0.001)\), plan and edge-angle \((p=0.002)\), plan and contact material \((p=0.005)\), edge-angle and contact material \((p=0.006)\) and longitudinal plan and edge-angle \((p=0.045)\) (Chapter 7, pg163). However, despite the existence of several interactions affecting the generation of scar sizes through use, only two of them also impact upon effectiveness. These are plan with edge-angle and plan with contact material.

The interaction of plan with edge-angle showed higher proportions of large scars occurred on convex/low combinations and may have contributed further to the high performance levels of convex/low combinations sawing activities. Low edge-angles incurred greater proportions of large, and very large, scars than high edge-angles, with convex being the only plan which sustained large scars with a high edge-angle (Chapter 7, pg 166). Similarities in the performance levels of concave and convex plans, when combined with high edge-angles, may in part be explained by the similarities evident in the number and types of scars incurred by both plans.

The interaction between plan and contact material shows that tiny and small scars dominate the scar sizes on soft wood while medium to large scars occur in greater numbers on hard wood. Convex plans incur a greater proportion of large scars than any other plan on hard or soft wood, while straight plans are more susceptible to small scars on hard wood and tiny scars on soft (Chapter 7, pg 167). In this case again, the higher susceptibility of concave plans to incur larger scars on hard wood than on soft may have contributed to their enhanced performance on hard wood (see Chapter 8, pg 199). Likewise, the equal proportions of small scars incurred by concave and convex plans on soft woods may have contributed to their equal performance levels. However, the higher incidence of large and medium sized scars on convex plans used to saw hard wood does not correspond with performance levels. These results, coupled with the fact that many of the interactions found to affect scar sizes did not affect performance levels supports the argument that scar features alone cannot account for noted variations in performance in either scraping or sawing activities.
CONCLUSIONS

A number of important conclusions regarding edge scarring and effectiveness can be made from the results presented in this chapter.

In general, edge effectiveness may be said to decline with use, each interval removing less material or cutting a shallower groove than in the previous interval. However, the occurrence of scarring reduces the rate at which productivity declines and increases the number of strokes able to be performed by that edge. The greater the number and the bigger the size of the scars incurred the larger the enhancement to the edge performance of the edge and the longer it is able to perform. This is an important observation for functional analyses, given the widespread belief that scarring is a negative outcome of use, dulling the edge and reducing both productivity and longevity (e.g.). Under controlled circumstances, for as long as scarring occurred, the nature of the working edge changed with new contact areas being created and other retired with use. When scarring ceased and the edge stabilized performance declined more quickly.

In addition to frequency, various features of the scars themselves incur some functional advantage on the working edge. In scraping activities, scar orientation affects performance with scars orientating from the non-contact to the contact surface found to be more effective than those emanating from the contact surface. In sawing activities, both initiation type and scar size are found to slightly enhance performance. These results indicate that an even greater range of variables contribute to edge performance than previously thought. Not only are morphological and use-related variables and interactions between them found to impact upon edge performance, but so too does the edge’s susceptibility to scarring, and in some cases, the nature and number of initiations, or the sizes and orientations of the scars incurred by the edge. As such, the relationship between artefact form and function becomes increasingly complex.

Divergence, in some cases, between variables identified as impacting upon edge performance and those found to enhance susceptibility to scarring indicate that, while scarring is capable of enhancing an edge and prolonging utility by maintaining an edge, it is unable to compensate for poor performing morphological combinations. Scarring alone is not responsible for edge effectiveness, with highest performing combinations of morphological features the primary contributors to performance.
In the final chapter of this thesis, the importance of these results, outlined in the previous four chapters, are examined in an archaeological context. Comparisons are made between current theory, these discoveries and important areas for revision and more critical interpretation of stone artefact assemblages are highlighted.
CHAPTER 11

RESEARCH OUTCOMES, IMPLICATIONS AND CONCLUSIONS

INTRODUCTION

Over 99% of human history is represented in the archaeological record by stone artefacts. As such, the accurate interpretation of prehistoric life and hunter-gatherer subsistence is largely dependent upon our ability to understand and interpret stone artefact assemblages. As an important means of facilitating prehistoric subsistence by enhancing hunter-gatherers' ability to negotiate the environment around them, understanding the functions of stone artefacts has long been an important research focus for lithics analysts and for the field of archaeology as a whole. A number of interpretive frameworks and techniques have now been established in an attempt to enable the accurate recognition and determination of both individual artefact functions as well as that of various technological systems and strategies. However, the importance of understanding stone artefact function and its relationship to the morphological variability represented in archaeological assemblages necessitates continued re-evaluation and assessment of current approaches in order to increase interpretive accuracy and enhance our knowledge of stone artefact assemblages and the prehistoric behaviours they represent. Based on highly controlled and systematic experimental procedure, the research presented in this thesis has tested a number of previously untested and often implicit assumptions upon which current interpretations of artefact function are based. In so doing, a number of crucial errors and their implications for the interpretation of stone artefacts have been highlighted and important areas for future research identified. This last chapter combines each of the arguments presented in the previous chapters in order to illustrate the necessity of adopting alternative approaches to the investigation of artefact function and of establishing an appropriate theoretical framework for exploring notions of artefact function within a wider behavioural context. It is imperative that archaeologists shift current perceptions of stone artefacts if higher levels of understanding of the behaviour of hunter-gatherers in the prehistoric context are to be achieved.

This chapter begins by addressing each of the five questions detailed in Chapter 1. These questions range in scope and purpose from the theoretical re-evaluation of current
approaches to the independent testing of these models by experimentation and identification of vital areas for future research. A discussion of the broader implications of these results for investigations into artefact functions and analyses of stone artefacts follows. The results presented in this thesis challenge current theories of the interpretation of artefact function and indicate that the relationships between form and function are much more complex than previously thought. The emerging view of the relationship between artefact form and function is that of a dynamic and interactive system in which adjustments in one aspect of morphology affect a number of other aspects, each with important consequences for the subsequent use and later interpretation of stone artefact function.

**Question 1: How robust are the principles of use wear/microwear analysis?**

Initial observations of the many dissimilarities between wear patterns produced under known circumstances and the poor results of blind tests (e.g. Gendel and Pirnay 1982; Newcomer et al. 1986; Unrath et al. 1986; Bamforth et al. 1990; Young and Bamforth 1990) suggested the existence of problems in current principles of wear analyses. The existence of many problems was confirmed in the discussion in Chapter 2 of the construction of the principles of wear analysis in which a number of crucial problems were identified with the widely accepted experimental protocol upon which current principles are based.

Of primary concern is the widespread inability of analysts to attain internal validity within individual experimental programs by controlling relevant variables. In each of the experimental programs discussed in Chapter 2, a maximum of five variables were held constant in any single experimental program, while in some cases the effects of up to 11 variables remained unaccounted for and uncontrolled (e.g. Tringham et al. 1974; Kamminga 1982; Vaughan 1985; Fullagar 1986; van Gijn 1990; Martindale and Jurakic 2006). In many cases, uncontrolled variables included both use-action and contact material (e.g. Semenov 1964; Tringham et al. 1974; Anderson 1980; Keeley 1980; Kamminga 1982; Moss 1983a; Vaughan 1985; Fullagar 1986; Levi Sala 1988; van Gijn 1990): the two variables argued to have the greatest impact upon the generation of distinctive variation in wear. As such, necessary and sufficient conditions of causality between artefact use and the wear generated could not be produced, despite a general belief to the contrary (e.g. Hayden and Kamminga 1979; Lewenstein 1981; Moss 1983a; Bienenfield 1985; Levi-Sala 1988; Borras 1990; van Gijn 1990; Fullagar 1994; Grimaldi and Lemorini 1995; Hardy 1999;
Kealhofer et al. 1999; Shen 2000) rendering the effects of each of these variables unknown and unquantifiable. It is not possible to argue, with certainty, that differences in the patterns of wear produced through use in those experiments were the product of either contact material or use-action.

Additional problems have arisen in giving priority to contact material and use-action as the primary determinants of wear. In general, analyses have failed to adequately explore the effects of other variables recognised to contribute to observed patterns; these include edge-angle, contact angle and applied force among others. A second consequence has been failure to identify all relevant variables with the likely existence of confounding variables in the form of morphological attributes of the working edge. Despite several existing lines of evidence suggesting edge morphology may have a profound effect on the wear developed through use, analysts have failed to prioritise these attributes in investigations of wear.

Each of these flaws has acted to introduce bias into the experimental procedure. The inconsistent treatment of relevant variables, both within and between experimental programs, inadequate control of relevant variables and the presence of confounding variables will have patently weakened the explanatory power of results generated under these circumstances, calling into question the validity of interpretations based upon them. It therefore seems inevitable that the current principles of wear analyses may be incorrect, being inseparable from the fundamentally flawed experimental procedures upon which they are founded.

**Question 2. Have wear analysts explored all of the key issues necessary for understanding artefact function?**

Current problems with wear analyses were shown in Chapter 3 to extend beyond the identification of microwear to the theoretical frameworks within which experimentation and interpretation are conducted. Approaching the functional interpretation of stone artefacts in accordance with traditional typological frameworks, wear analysts have imposed interpretive limits upon themselves, constructing a system of analysis that is self-reinforcing and precludes the discovery of alternative views of artefact function.

Belief in typological assumptions that equate form with function, and retouch with use, meant analyses have been dependent upon, and dictated by, entirely untested notions of the relationship between form and function. Despite increasing evidence provided by both technologists and wear analysts indicating that assumptions of direct and simple
correlations between form and function do not exist, wear analysts have continued to focus functional investigations towards understanding formal types and analyzing assumed functional edges. These decisions have come at the expense of testing and exploring more behavioural explanations of artefact variability, such as those provided by sequence modeling which view variability as the product of multiple changes in edge morphology through use and maintenance activities. Further, the focus on formal types has often resulted in widespread neglect of unretouched forms that have now been demonstrated to perform the same range of functions as many formalized retouched counterparts (e.g. Fullagar 1986; Keeley 1980a; Keeley and Toth 1981; Odell 1981b; Moss 1983a; Shea 1988; Aldenderfer 1990; Hayden 1990; Grimaldi and Lemorini 1995; Lemorini et al. 2006).

A final, but crucial, area of neglect relates to the exploration of all aspects of artefact function including the specific features that contribute to artefact performance and the scale at which they operate on individual artefacts. The failure of wear analysts to explore reasons why a given morphology might be used in a particular way, what it is about an artefact that lends itself to specific functions, or whether or not the artefact is even capable of performing the functions attributed to it, means that we are ignorant of critical aspects of artefact function.

These problems indicate that, to date, wear analysts have failed to explore some of the most fundamental issues relating to artefact function, the most important being the relationship between artefact performance to morphological variability. Future investigations into artefact function should seek to rectify these problems in order to better understand the relationship between artefact function and morphological variability.

**Question 3. How well do models of the organization of technology contribute to an understanding of artefact function?**

Integrating strategies of tool design, the staging of tool manufacture and use and the reuse of artefacts into broader models of hunter-gatherer behaviour in different social, economic and environmental conditions, models of the organisation of technology represent some of the most exciting, innovative and promising models currently available for understanding and interpreting variation in stone artefact assemblages. However, as shown in Chapter 4, the need to be able to identify qualities such as flexibility, versatility, portability, maintainability, specialization, generalisation and so on in an archaeological context has meant that, until now, many of these models have been untestable. In the absence of
information explaining the relationship between artefact morphology and the successful execution of specific tasks, it has not been possible to test whether each of these desirable qualities is detectable in an archaeological context. At present archaeologists are unable to determine which morphological characteristics are required to fulfill basic functional requirements. As such, differentiation between minimal performance requirements and more desirable qualities, such as portability and flexibility, on the basis of morphological difference is also not possible, being reliant upon a greater understanding of artefact performance than has been available to date.

Further, few of these models explore the functional implications of the assumptions they make about artefact performance and efficiency. While artefact morphology and assemblage composition are argued to indicate various technological strategies in the archaeological record, the effects of adjustments to morphology to suit technological requirements such as flexibility and maintainability are not considered. The effect of decreasing artefact size on function to meet mobility requirements is one such example (e.g. Torrence 1983; Shott 1986; Kuhn 1994). As such, a number of the assumptions upon which these models are based remain untested.

Finally, the focus of organisation of technology models on individual causes of variability indicates a general failure to recognize that individual tools represent dynamic entities which are responsive to a number of interacting variables. The emphasis of one source of variation over another imbues that variable with greater responsibility for morphological change than may be the case and denies the effects of any number of extraneous variables contributing to the technological circumstances. In failing to accommodate for the effects of extraneous variables, these models are incapable of internal validity or of making causal statements relating morphology to technological systems, due to the likelihood that bias has been introduced by any number of additional variables.

These problems indicate that much of the promise and interpretative value of models of the organisation of technology is not attained because of the inability to validate these models in an archaeological context. A clear understanding of the performance characteristics of stone artefacts is essential before morphological markers, distinctive of various design strategies, can be identified in the archaeological literature.
Question 4. How should investigations into artefact function proceed?

Analysis of the current approaches utilized by archaeologists to explore and interpret artefact function has highlighted a number of crucial areas of improvement for future investigations of artefact function. The first of these is the need to adhere to appropriate experimental protocol in order to generate accurate and relevant data. If causal relationships between use and wear or form and function are ever to be identified, it is imperative that bias is eliminated, or minimized, through the equal treatment and control of all relevant variables. Failure to do so necessarily reduces the interpretive value of the research.

A second requirement is that all relevant variables be thoroughly explored. This includes morphological variables likely to affect the development and interpretation of wear and those that contribute to the overall performance of the artefact. The current failure to thoroughly explore all relevant variables has greatly reduced the explanatory power of the previous investigations into artefact function by introducing unquantified, and often unidentified, bias and negating the ability to identify unique causal relationships.

A final necessity is the establishment of an appropriate theoretical framework within which to test models of artefact function. This requires the generation of clear definitions of the concepts being tested as well as a framework, within which to test and interpret any data that is produced. The existing literature on performance characteristics derived by ceramics analysts offers an ideal place to begin constructing similar frameworks more particular to exploring performance and function in stone artefacts. It has been the absence of such a framework that has enabled so many aspects of artefact function to be overlooked in previous investigations of artefact function.

Question 5. What are the morphological and use variables affecting artefact function?

The experimental program outlined in Chapter 6 was specifically designed to explore the nature of the relationship between edge morphology and performance in accordance with the recognized requirements of how investigations into artefact performance should proceed (see above and chapter 5). The results of this program, discussed in chapters 7, 8, 9 and 10, revealed an exciting and dynamic relationship between morphology and performance which included the existence of high performing combinations of variables,
trade-offs and compromises and a number of interactions between variables which result in morphologically dissimilar functional equivalents.

Of primary importance was the discovery that, under controlled circumstances, each of the variables tested (that is edge plan, profile, edge-angle, relief-angle and contact material) had a statistically significant effect on edge performance in scraping activities and all but longitudinal plan had an effect on performance in sawing activities. This discovery illustrates that the relationship between form and performance is extremely complex with much further work in this area required before artefact performance and function can be properly understood. Nevertheless, the results generated in this thesis represent an important starting point from which other studies can be built, suggesting general relationships and interactions for further research. These results can be summarized as follows:

1. Both morphological and use variables have a significant effect on edge performance, suggesting that other as yet untested variables may also contribute to variations in edge performance. These results highlight the complexity of the existing relationship between form and function.

2. Certain combinations of features perform better than others. However, it is also possible for a range of different features to produce similar levels of performance and longevity both within the same task, and in some cases, between them.

3. Trade-offs exist between forms such that the tool user may be forced to choose between performance and longevity.

4. Compromises in performance levels are possible whereby poor performing artefacts can be compensated for by combination with higher performing features. The cost of compromise to the tool-user may be the number of strokes required to complete a task.

5. Differential rates of material loss with time results in certain combinations being better for short term use and others for long term use.

6. Use-scarring has a positive affect on performance, with rates of material loss increasing with each scarring event in proportion to the number of scars incurred. Artefact use-lives are affected in a similar way by scar frequency with each scar increasing the number of productive strokes the edge is able to perform.
In addition to addressing the specific research questions posed, the results presented in this thesis have wide reaching consequences and implications for the future interpretation and analysis of stone artefacts and for the tool using behaviours responsible for their creation. These are addressed individually below.

**FALLACIES IN WEAR ANALYSES**

One of the most striking observations to be made from the results discussed in this thesis is their contradiction of results generated in previous studies. As such, many appear to be counter-intuitive, being in direct opposition to what has been reasonably supposed to result from various modes of use. This ability to produce such dramatically different results, under controlled circumstances, suggests that in addition to poorly conducted experimental programs, problems exist in the intuitive and theoretical concepts upon which wear analyses are based. These have resulted in the propagation of a number of interpretive fallacies regarding the ability of wear analyses to construct valid interpretations of the functions of stone artefacts. These are discussed in detail below.

**Causes of Variation in Scar Patterning**

The principles of wear analyses have been very much dependent upon what has, until now, been considered reasonable explanations of the processes involved in generating use-scarring. This can be best exemplified by drawing from the seminal work of Tringham et al. (1974), which is one of the most widely cited of all experimental programs into the development and distinctiveness of use-scarring (e.g. Ascher 1979; Cantwell 1979; Schiffer 1979; Stafford and Stafford 1979; Tsirk 1979; Spear 1980; Lewenstein 1981; Patterson 1981; Dumont 1982; Kamminga 1982; Walker 1983; Siegel 1984; Bettison 1985; Bienenfield 1985; Corruccini 1985; Sussman 1985; Fullagar 1986; Akoshima 1987; Tommenchuk 1988; Schultz 1992; Shea 1992; Shea and Klenck 1993; McDevitt 1994; Richter 1996; Van den Dries and van Gijn 1997; Madsen 1997; McBrearty et al. 1998; Shen 2000; Alvarez et al. 2001; Becker and Wendorf 2005; Lemorini et al 2005; Stemp and Stemp 2001; Martindale and Jurakic 2006; Rots et al. 2006; to name only a few publications citing the work). The goal of Tringham et al's (1974) work was to test the hypothesis that 'A tool made of specific raw material, whose edge is activated in a specific direction across a specific worked material will develop a distinctive pattern of edge damage of a kind that is recognizable on the edges of prehistoric tools' (Tringham et al. 1974:178).
A number of variables were recognized by Tringham et al. as potentially affecting scarring including spine plane angle, edge morphology, action, pressure applied during use and contact material. For several of these variables, Tringham et al. admitted that systematic testing had not been performed. Nevertheless, for each variable common-sense or intuitive explanations of their effects on scarring were provided. For the purposes of discussion these are summarized briefly below along with their physical manifestations as functional indicators on the used edges of artefacts:

- **Spine Plane Angle** — argued to affect susceptibility to scarring with low edge-angles thought to be weaker and sustain higher frequencies of scars, than high edge-angles. However scar features are said to remain tasks specific.

- **Surface curvature** (equivalent to longitudinal profile as discussed in this thesis) — argued to prevent continuous contact with the worked material along the edge and result in uneven distribution of scarring along the edge.

- **Edge protrusions** (equivalent to edge plan as discussed in this thesis) — thought to produce more, or less, damage in the spot where either the convexity or concavity occurs. The distinctive characteristics of action and material appear to a greater or lesser extent depending upon which shaped edge is used.

- **Action** — the edge of the flake in contact with the material is considered to represent a striking platform in the same way that flakes are removed from a striking platform through knapping. It is therefore argued that flakes will be removed at those loci along the edge where the pressure from the worked material is great enough. As such, mode of action is distinguished by the distribution of the flake scars along the two surfaces of the edge with ‘the amount, regularity, and direction of pressure, with varies with each action, ... directly reflected in the detachment of the microflakes’ (Tringham et al. 1974:188). In sawing activities, scarring is therefore argued to occur equally on both aspects of the edge, while the application of pressure to only one aspect during transverse actions dictates that scarring will occur along just the one aspect only and are regular in size and shape (Tringham et al. 1974: 189). Step terminations are also argued to occur more commonly in longitudinal actions than in transverse tasks, due to the nature of the force applied in these actions.

- **Contact Material Type/Hardness** — argued to be reflected in the features of the scars produced. Variation in the hardness and resistance of the material worked is
reflected in corresponding variation in the size and shape of the scars produced. The harder the material, the more rapidly flakes are detached and the larger and deeper are the scars produced. Step and hinge terminations are argued to be produced only on hard materials, including hard wood.

These explanations of important variables and the accompanying explanations continue to proliferate in the wear literature today and form the basic markers for identifying artefact function through low-powered magnification. This is because not only do Tringham et al. 1974 continue to be cited in even the most recent publications, but so too do many of the subsequent researchers who have adopted the same definitions of wear and have, in turn, become widely referenced, with examples including Odell and Odell-Vereecken (1980 and Odell 1980, 1981, 1985a, 1985b - referred to by Lewenstein 1981; Olaussen 1983; Siegel 1984; Allen 1985; Salls 1985; Akoshima 1987; Ramos Milan 1990; Grimaldi and Lemorini 1992; Schultz 1992; Collins 1993; Richter 1996; Crombe et al. 2001; Stemp and Stemp 2001; Donahue and Burroni 2004; Fullagar and Jones 2004; Becker and Wendorf 2005; Lemorini et al 2005; Rots et al. 2006), Kamminga (1979, 1982 and referred to by Fullagar 1984, 1986; Siegel 1984; Allen 1985; Boot 1986; Sussman 1988; Richter 1996; Hardy and Garufi 1998; Fullagar and Jones 2004; Rots et al. 2006) and Shea (1987, 1988, 1989, 1991, 1992 - referred to by Hardy and Garufi 1998; McBrearty et al. 1998; Tsirk and Parry 2000; Grimaldi and Lemorini 2005; Lemorini et al. 2005; Martindale and Jurakic 2006; Rots et al. 2006). A result is the global perpetuation of principles and ideas of use-wear based on intuitive ideas of how wear should develop and where we would expect to find it. Each of these ideas has then been further supplemented by results generated through poorly constructed experimental protocol. However, the results presented in this thesis indicate that, under controlled conditions, almost all of the principles outlined above are incorrect.

For example, while low edge-angles were found to scar significantly more frequently than high edge-angles, they were also found to result in a higher proportion of V-D orientated scars, low to moderate proportions of hertzian initiations depending on the longitudinal profile used, various proportions of feather terminations depending upon the plan, longitudinal profile or relief-angle used and different proportions of scar sizes depending on the relief-angle used. These results contravene those forwarded by Tringham et al. (1974), revealing that far from impacting upon scar frequency alone, edge-angle has a statistically significant affect on the development of each of the features of scars previously considered to be diagnostic of artefact function. The relative proportions of scars with bending initiations, D-V orientations and step terminations as well as the sizes of scars
produced through use, will each differ in accordance with the angle of edge used and its interactions with other relevant use, and morphological, variables (see Chapter 7).

Similarly, contrary to simply altering the location and intensity of scars along the working edge, variations in the edge curvature (longitudinal profile) and protrusions (edge plan) were found to have many statistically significant effects on both scar frequency and scar features. In both scraping and sawing activities longitudinal profile and edge plan were each found to affect scar orientation, initiation type, termination type and the range of scar sizes produced, each in different ways. Though unexpected, in terms of the previous literature, the effects of these variables upon the development of scarring necessarily means that the basic assumption that regardless of edge morphology, all artefacts used in the same actions against the same contact materials produce similar patterns of scarring, is invalid.

Misconceptions also exist in the use of scar sizes and features as determinants of contact material hardness. Tringham et al. (1974) predicted that harder materials, acting as harder indentors, will produce larger scars, more rapidly and with a greater frequency of step and hinge terminations than occur when working softer materials. Tringham et al. (1974) classed ‘soft’ materials as hide and meats, ‘medium’ materials as soft to medium woods, and ‘hard’ materials as bone, antler and hard woods. As such, it cannot be argued that the dichotomy between hard and soft woods experimented within this thesis are equivalent to the dichotomy between hard and soft materials defined by Tringham et al. (1974). However, if the principle is sound, it can be expected that harder materials would produce greater frequencies of each of these features than would softer materials. This was not found to be the case, with feather terminations consistently found to be more common on harder wood (except where relief-angles are low in scraping activities) and scar frequencies and sizes found to be greater on softer wood than on harder wood (see Chapter 7). In addition, evidence that statistically significant interactions exist between plan, longitudinal profile, edge-angle and relief-angle on the frequencies of feather terminated scars produced through use, makes it impossible to establish a causal relationship between contact material hardness and termination type. Likewise, the observed effects of multiple significant interactions between plan, profile, edge-angle and relief-angle on scar sizes and frequencies for both scraping and sawing actions means that it is simply not possible, at present, to make blanket statements regarding the sizes or frequencies of scars likely to be produced by a particular contact material or resistance.
The final variable argued to produce distinctive wear by Tringham et al. (1974) and subsequent analysts is use-action. However, the experimental results presented in Chapter 7 indicate that each of the scar features previously used to represent particular use-actions is, in fact, the product of multiple statistically significant interactions between all five of the use and morphological variables tested. The most commonly referenced indicator of use-action is scar orientation in which scars emanating primarily from the one surface are argued to indicate scraping activities while those emanating in even numbers from both surfaces are attributed to sawing activities (e.g. Tringham 1971; Tsirk 1979; Anderson 1980; Odell 1980, 1981; Dumont 1982; Kamminga 1982; Fullagar 1986; Akoshima 1987; Tomenchuk 1988; van Gijn 1990; Shea 1992; Shea and Klenck 1993; Alvarez et al. 2001). Under controlled conditions, this relationship does not hold true, with an equal number of ventral to dorsal and dorsal to ventral orientated scars found to occur on edges used both in sawing and scraping activities. There was no significant effect of action on scar orientation. In addition, higher frequencies of step terminated scars were not found to occur from sawing activities. The identified effects of interactions between plan, profile, edge-angle, relief-angle and contact material again indicate that scar termination type is affected by a wider range of variables than use-action alone, signifying that direct correlations between termination type and action are impossible to make.

Tringham et al. (1974:191) also note that scar frequency is an important determinant of action and contact material, stating 'It is also clear that there are great differences in the rate of the formation of edge damage. However, it is not the case that given enough time all worked materials will eventually produce the same wear pattern' (emphasis is Tringham et al.'s). Yet the results presented in Chapter 7 again contradict these assumptions, showing that in scraping activities, length of use was the most significant determinant of scar frequency, followed by edge morphology. In sawing activities, length of use alone was found to determine scar frequencies. In neither activity were other use variables found to have any effect on scar frequency, contrary to the assertions of Tringham and other researchers.

The ability for so many of these results to contradict previously published principles indicates that the systems currently used for interpreting wear are wrong. The processes acting upon edges during use and the mechanisms responsible for producing wear have clearly been misunderstood. Of fundamental importance is the recognition that the causes of wear are far more complex than we have previously been led to believe, with a host of hitherto unconsidered morphological variables making significant contributions to the
development of scar features and frequency through use. Importantly, statistical analyses show the morphological features of the working edge to be at least as significant, and in most cases, more significant contributors to the proportions and frequencies of scar features. The sources of variation in edge patterning through use have therefore been entirely misunderstood.

Differences in artefact functions are reflected in the development of distinctive patterns of use scarring

The most important consequence of the failure of wear analysts to identify the relevant causes of variation in wear and the mechanisms responsible for its development has been the perpetuation of the fundamental assertion that different functions produce unique and identifiable differences in the resultant use-wear traces. While the research presented in this thesis related specifically to the identification of artefact function from use-scarring and not additional types of wear, the results are central to the field of use wear analysis; revealing that differences in the features and frequencies of scars produced through artefact use cannot be shown to be distinctive of either contact material or use-action.

The existence of multiple significant interactions between both use and morphological variables affecting the nature and number of scars produced through various actions (see Chapter 7), indicated that simple and direct comparisons between artefact function and scar patterning cannot be justified. Not only does substantial variation in scar patterning occur between edges used to perform the same function, but even greater complexity exists in differentiating between wear produced by different activities. The extensive overlaps in the range and proportions of scar features produced by sawing and scraping both hard and softer woods revealed in Chapter 7 indicated that distinctive differences in the number or types of scar features produced by each of these functions did not exist. Large degrees of overlap in the features produced by each action and contact material meant that none of the features, or combinations of features, could be regarded as distinctive. As such, within the confines of present knowledge, it appears that an identifiable relationship between artefact function and scar patterning does not exist.

The relationship between edge morphology and wear is clearly much more complex than has been previously considered, with a substantially wider range of causal relationships existing. For each scar feature investigated in this thesis, between one and six interactions existed between the five variables tested (plan, longitudinal profile, edge-angle, contact
material, relief-angle). The range of significant interactions between relevant variables prohibits the identification of necessary conditions of causality between any variable and resultant scarring wear.

**Site function is reflected in stone artefact assemblage composition**

The discovery that various features of edge morphology have an equal, or more significant, effect on scar patterning development than do use related variables has a number of important implications for interpretations of site function, based on assemblage composition and diversity. The inability to differentiate artefact functions on the basis of scar patterning, combined with the effects of edge morphology on the development of wear, means that many differently shaped edges may be used to perform the same function, but develop entirely different patterns of scarring. Likewise, working edges with identical morphological features may be able to produce quite similar scarring patterns despite being used to perform very different functions. This means that discriminating between different functions performed on similar morphologies, or the same functions performed by very different morphologies, are not possible on the basis of scar patterning alone. The problem arises of how to interpret variation in wear within an assemblage or implement type when so many different causes of the observed patterning exist. As such, differences and similarities in the scar patterning observed on archaeological specimens are not sufficient to indicate functional difference/similarity between artefacts. Previous interpretations based on the invalid assumption that difference in wear equates to difference in function, must therefore be re-evaluated.

**Moving beyond the fallacies**

The fact that so many of the results presented here may be considered ‘unexpected’ indicates that, at present, analysts are simply ‘expecting’ the wrong things. Inadequate experimental control, failure to identify all relevant variables and an inaccurate understanding of key mechanisms affecting wear are mistakes that have proved costly to the credibility of the use-wear field. While it may be said that scarring is only one of several types of wear utilized by analysts to interpret artefact function, the ability to identify so many problems with use scarring by exploring approaches to the investigation of wear analyses as a whole suggests that alternative forms of wear are likely to be equally susceptible to the same kinds of problems. The potential for an entire generation of wear analysts and archaeologists to have constructed interpretations of prehistoric site functions
and explanations of prehistoric behavioural systems on principles that are largely, if not entirely invalid, now seems incredible.

While the founding figures of wear analysis, such as Semenov, Tringham et al. and Odell have constructed statements relating scarring to function which have served for more than thirty years as the primary point of reference for wear analyses of this kind, they now appear to be fallacies. The onus is on the next generation of wear analysts to do justice to the pioneering work of these early analysts by seeking to better understand the processes involved in the development of all types of wear and in identifying legitimate means of differentiating artefact functions on the basis of known and tested causal relationships between use and the wear it creates. The improvement of experimental protocol, identification of all key variables, specific explorations into the processes responsible for producing wear and the establishment of an appropriate framework for interpreting it, will be critical to the ability of wear analyses to reestablish its credibility as a viable method of interpreting stone artefact function.

**MYTHS OF FUNCTIONALLY EFFICIENT TOOLS**

The investigation into stone artefact performance presented in this thesis represents one of only a handful of studies conducted in this area of lithics analysis. It is therefore important to note that, in the absence of substantial evidence on the topic of artefact performance, it has still been possible to identify several instances in which experimental results contradict current assumptions of what makes a functionally efficient tool. Assumptions that all stone tools were efficient in some way, simply by virtue of their existence, have been central to arguments about the organization of technology (see Chapter 4). However, the results presented in this thesis reveal that considerable differences exist between the performances of different edge morphologies, such that the decision to utilize one morphology over another may result in considerable differences in the speed and efficiency with which a task may be completed.

**Straight is great? Edge morphology and performance**

Evidence of how flaked stone artefacts are believed to function or which precise features of an edge are thought to contribute to performance are rare in the archaeological literature. However, it is generally asserted that, except where specialist activities are involved, the most productive edges are straight in plan and profile. Statements such as 'An edge straight in section is a desirable working unit....a curved edge is not efficient,
either in terms of completing the task or in terms of conserving the tool’ (Moss 1983a:237) and ‘Edges that are straight in section are the most efficient for cutting, planing, whittling and sawing, and they are also the least likely edge morphology to sustain damage in use.....it is therefore reasonable to suppose that prehistoric people preferred straight edges’ (Moss 1997:199) have also been echoed by a number of wear analysts (e.g. Tringham et al. 1974; Grimaldi and Lemorini 1995), some of whom have chosen to focus their attention on artefacts with straight edges on this basis (e.g. Grimaldi and Lemorini 1995).

The results presented in Chapters 8, 9 and 10 indicate that this assumption is misleading on several levels. Under controlled conditions, straight edge plans were found to experience the highest failure rates for long term usage in sawing activities, as defined by the experimental program. While these rates are lower when working with softer wood and low edge-angles, straight plans consistently had the highest predicted failure rates for longevity. Likewise, performance levels indicated that edges that are straight in both plan and profile were consistently the lowest performing combination of features for scraping activities while straight plans, combined with any profile, were the lowest performing morphologies in sawing activities. Due to the different effects of each variable with use-action, improvements in the performance levels of straight edges in sawing activities were only identified to occur by reducing the size of the edge-angle used. In scraping experiments, however, the effects of interactions between plan and profile on edge performance indicated that distinct advantages existed with the use of straight edges when involved in 'complex edges' that is, when combined with concave or convex shaped edges in the alternate dimension. The functional advantages for a tool user by utilizing a complex edge in favour of the straight/straight plan/profile combination traditionally assumed to achieve high performance levels in all tasks, will differ according to its combination with additional relevant variables such as edge-angle and relief-angle, as well as any interactions with duration which change these effects over time. At a minimum however, it would take approximately 800 strokes longer for a straight/straight combination edge to achieve a similar level of material loss as that achieved by a concave/straight complex edge when scraping hard wood and increases to approximately 1100 strokes when scraping soft wood. Such a dramatic difference in the performance levels of these different morphologies should be sufficient to suggest that contrary to previous assumptions, many instances exist in which tool-users would be expected to utilise complex edges in preference to straight edges. The reasons why complex edges produce greater rates of return for strokes invested have not been explored in detail in this thesis and represent an interesting area for future investigations.
Edge scarring reduces performance?

Edge scarring is frequently assumed to have a destructive effect on edge productivity (e.g. Tringham et al. 1974; Tsirk 1979; Moss 1983a, 1997; Olaussen 1983; Grimaldi and Lemorini 1995), illustrated by comments such as ‘edge damage created during use implies an inefficient use of flint’ (Moss 1997:199). However, these assertions have not been supported by experimental data. Instead, scarring has been shown to enhance both the performance levels and survival rates of artefacts involved in both sawing and scraping activities, proportionate to the number of scars incurred by the edge (see Chapter 10). In addition, the larger the scars produced the greater the enhancement to edge performance. These results suggest that, contrary to indicating exhausted tools, an edge bearing heavy use scarring may instead represent an implement at the peak of its performing period.

While the advantages incurred by an edge through scarring were substantial, the combinations of morphological features noted to scar the most were not always the highest performers. This suggests that either edge morphology had a greater impact on performance than did susceptibility to scarring, or that the size and location of the scarring was sufficient, in some instances, to change the shape of the working edge - possibly to a lower performing combination of features. The ability for very subtle differences in the morphology of the working edge to result in quite substantial differences, in both the long and short term performance of that edge, suggests that it may be possible for use scarring to simultaneously sharpen and diminish the suitability of that edge for the task at hand. For example, a concave/straight complex edge commonly sustains edge damage on each of the two points of contact with the worked material on either side of the concavity. Subject to the degree of concavity exhibited by the edge, continued removal of artefactual material from these points by use-scarring might gradually result in an increasingly straight edge plan. The extent to which use scarring increases edge performance might therefore be dependent upon the original shape of the functional edge, the location and degree of scarring incurred, and its resultant effect on the shape of the new working edge. While further work is required before the specific effects of use scarring and morphological change on performance can be quantified, the potential for scarring to alter edge shape to either a more, or a less, productive form, indicates that universal statements relating edge damage to ineffectual artefact performance are misguided.

The paucity of previous experimental investigations into the performance characteristics of flaked stone tools is such that the basis for assumptions of the functional superiority of
straight and undamaged edges is unclear. It does, however, seem likely that analogies with modern tools such as chisels and knives are contributing factors, with comments such as 'a backed blade (or a blade with a blunted edge) resembles a penknife blade that one can deduce the function 'knife,' (Bordes 1969:3) suggestive of such an approach. What is clear is that stone artefacts do not function in the same way as modern steel implements. The results presented here indicate that analogies between modern and prehistoric tools have not served the field well with observations of contradictory evidence increasing. A clear need exists, to rethink such approaches and to explore new and more independent methods of understanding stone artefact function.

**Artefact morphology or edge morphology?**

One of the primary mechanisms by which analysts and archaeologists differentiate artefacts from one another is through morphological variability (see Chapters 2 and 4). Assemblage composition and diversity are used to determine the ranges of functions carried out at a site (from the number of different artefact forms) and the intensity of the function performed at the site (from the frequencies of each form present) in addition to other features of technology. Difference is assumed to relate to overall implement morphology with little, if any, attention paid to variation in artefacts at the smaller scale of individual working edges. Yet the experimental program conducted in this thesis shows that significant levels of difference in performance can exist and be enhanced, or diminished, at the level of individual functional edge alone. Only very subtle differences in the levels of one or two morphological variables are required to result in an edge that would attain high performance levels in quite a different function. It is therefore anticipated that two artefacts that appear identical at the implement level might have different functional abilities because they possess slightly different morphologies along functional edges. These results suggest that arguments which emphasize implement morphology as the primary determinant of difference will necessarily overlook crucial functional differences on a smaller scale. Differences between higher and lower performing tools will not be able to be distinguished by glances of overall morphology.

These problems will be particularly relevant to those researchers operating with typological systems of analysis, in which a single function is identified for each implement type and where functional edges are identified on the basis of morphology. Having identified a tendency for archaeologists to misguidedly emphasize the functional value of edges that are straight in plan and profile, it is likely that the edges which have been previously identified
to be functional edges were in fact not used at all, while important functional edges remain undetected. Further, the ability for up to five separate use zones to be identified on a single artefact (Shen 2000) means that failure to consider more than one function/functional edge on an artefact will have resulted in interpretations of site functions which grossly underestimate the true frequencies and ranges of tasks represented by the assemblage.

In light of this evidence it is probable that previous approaches to the differentiation of artefact function by overall implement morphology have been operating at a scale of observation that is ill-suited to the accurate differentiation of artefact functions. As a consequence, many important functional indicators are likely to have been overlooked, leading to misrepresentative interpretations of archaeological assemblages.

**Reduction and artefact use-lives?**

Artefact use-lives are generally assumed to be reduced, or extended, relative to the nature and type of the retouch applied (e.g. Kuhn 1994; Shott 1994; Shott and Sillitoe 2005). Unidirectional, or percussive, retouch removing large quantities of raw material is argued to reduce the potential for extended use-life relative to pressure flaked bifacial retouch which removes considerably smaller amounts of material per retouch episode, thereby enabling greater amounts of cutting edge to be produced from the same quantities of raw material. As such, a heavily retouched artefact is considered to indicate the extension of its use-life. However, as identified in Chapter 7, the ability for certain functional edges to maintain performance levels longer than others, indicates that the use-life of an artefact might also be extended by utilizing edges with greater edge holding properties. On average, concave edge plans with low edge-angles, experience failure rates that are 30 percent lower than those experienced by straight plans with either high or low edge-angles after 1200 strokes and 18% less after 2400 strokes on hard wood. These differences are more dramatic on softer wood, with concave plans experiencing more than half the failure rates exhibited by straight plans after both 1200 and 2400 strokes. This ability for particular edges to remain productive for longer periods of time before requiring modification suggests it is possible, in some cases, for an unretouched edge to represent the same amount/intensity of use as a retouched artefact, simply by holding its edge longer and requiring less retouch to complete the same job.
While previous published interpretation have related use-life to reduction capacity only, the results presented here indicate that extension of use-life may occur prior to retouch in certain morphologies, by extending the amount of work able to be performed before retouch is necessary at all.

**Future explorations of efficiency**

A number of untested assumptions relating to the functional efficiency of stone artefacts currently proliferate in the archaeological literature which the results presented in this thesis show to be incorrect. The two most important points of divergence from previous assumptions are the scale at which performance operates - at the level of edge rather than implement, and the recognition that stone artefacts function differently to their steel counterparts. The ability for current assumptions to be so misguided is likely to be the product of minimal research conducted into this crucial aspect of hunter-gatherer subsistence and the reliance upon untested assumptions. The recognition that current assumptions are invalid necessitates the discovery of more appropriate interpretative systems in order to better understand relevant phenomena and to increase the accuracy of interpretations of stone artefact assemblages.

**THE UNFORESEEN DYNAMISM OF STONE TOOLS**

One of the most exciting outcomes of the research presented in this thesis is the discovery that stone artefacts represent much more dynamic and interactive entities than has been previously thought. Individual functional edges have been shown to be dependent upon, and responsive to, a wide range of complex interactions between both use and morphological variables. Contrary to the static implement types previously depicted, which were manufactured for a specific purpose and discarded when the task was completed or when the artefact was no longer able to be retouched, the emerging view is that stone artefacts were capable of responding to all manner of circumstances by compromising forms, balancing trade-offs and performing a wide range of functions. These discoveries have important implications for ongoing investigations into lithic technology pertaining not only to the identification of artefact function, but also to a more appropriate reconceptualisation of stone tools within hunter-gatherer society.
Functional Dynamism

Stone artefact performance can now be understood as the product of multiple and complex interactions between a wide range of morphological and use related variables (see Chapters 7, 8 and 9). These interrelationships facilitate the existence of extremely high performing morphologies for tested actions, as well as affording hunter-gatherers some means of improving poorer performing morphologies through subtle enhancements to the morphology of the edge or the angle of use. Morphologically different functional equivalents have therefore been shown to exist in which substantial compromise in morphology is able to occur without the knapper suffering dramatic penalties in tool performance or longevity. Trade-offs have also been identified in which hunter-gatherers may have been forced to choose whether to enhance longevity or performance, with many morphologies shown to be unable to enhance both traits. The level of functional flexibility afforded by these complex interrelationships between variables means that simple and direct correlations between morphology and function simply cannot be justified. The nature of these interactions is such that all actions will have immediate reactions that will flow on to affect other aspects of artefact performance as use continues; a slight shift in edge plan shape or angle will be sufficient to affect both the number of strokes required to complete a task as well as the artefact’s capacity to complete the required number of strokes without modification. As such, no single variable can be considered in isolation from other relevant variables, indicating that every detectable difference between artefact edge morphologies will have had wider implications for its function within hunter gatherer subsistence systems.

This evidence lends partial support to both of the two possible functional outcomes of ‘sequence modeling’ discussed in Chapter 3, to explain the relationship between form and function as morphology changed through use, reuse and maintenance activities. The first outcome presupposed that the changes to edge morphology induced by maintenance activities would have no effect on performance, with a wide range of variables able to achieve similar performance levels. However, the second outcome predicted that changes would have varying effects on performance with directional changes in the reduction of the edge, resulting in either an increase or decrease in productivity. Existing dynamic interactions between relevant functional variables indicate that both of these outcomes are likely to occur, depending on the degree of change incurred by the edge through maintenance, and the performance levels of the original edge prior to rejuvenation. Substantial changes to the edge have been shown to be possible without causing excessive
change in performance levels. The greatest flexibility in form, without causing significant compromise in performance, occurs between morphologies already experiencing similar levels of compromise in variables. It is, however, also possible for reduction to change the morphology of an edge to a less suitable form, a more suitable form or a morphologically different functional equivalent, by adjusting the performance values of the edge produced in each case. The extent to which performance increases or declines is dependent upon the number of compromises or deviations from the highest performing features that the new morphology represents.

For example, by changing a convex plan and straight profile scraper with a low edge-angle, to one with a high edge-angle and adjusting relief-angle accordingly, maintenance activities could increase the performance levels of that edge for scraping hard wood, but reduce its longevity. By comparison, a change from a straight/convex plan/profile with a high angle to a convex/convex plan/profile with the same edge-angle would result in a decline in overall productivity with use but would increase the short term benefits. However, the existence of combinations of features that produce highest performance levels for each activity and contact material, indicate that it is possible that, in some cases, a change may be so great that it changes the function for which that edge is best suited, at which point the tool user would have to choose whether to continue to use the new edge at a reduced capacity for that particular function, or to select a different tool and save the new edge for the task for which it is now best suited.

While considerable amounts of research into artefact performance, in a wider range of activities and on a greater variety of materials, are required before it would be possible to explore these ideas in greater detail, discoveries of functional dynamism in edge morphologies lend similar support to concepts of maintainable/generalised and reliable/specialised design systems central to arguments modeling the organisation of technology.

The existence of combinations of features that attain significantly higher performance levels supports the assertion that it is possible for specialized morphologies to exist and to function at a high level in the tasks required of them. However, the capacity for a single edge to perform well in several tasks; for several edges to perform the same task well, and for a single artefact to possess multiple functional edges, suggests that multifunctional tools may also exist. The capacity for compromises in features to occur facilitates some degree of morphological change without compromising performance and suggests that certain
edges may be both flexible and maintainable by allowing a degree of retouch to occur but to maintain functional equivalence. In addition, the ability of individual edges, rather than entire morphologies to contribute to performance, means it may be possible for a single artefact to be both specialized and generalized by utilizing different edges, which in turn allows it to be both flexible and versatile, and, by being only the one artefact, also portable.

However, while these results appear to support a number of the assertions forwarded in models of the organisation of technology, problems still remain in our ability to identify and differentiate between these technological solutions in archaeological contexts. The complexity of relevant variables identified in Chapters 8 and 9 and the possible number of morphologically dissimilar functional equivalents (Chapter 10) between just the two actions tested in this experimental program, suggests that differentiation of the basis of morphology will remain difficult to justify.

The identification of form from function

The ability for several morphologies to achieve functional equivalence enables a single task to be represented archaeologically by morphological differences relating to functional edge morphologies, in addition to those noted above relating to similarities in overall implement morphology. Likewise, the ability for certain combinations of features to perform several tasks equally effectively means that it is also possible for several tasks to be represented by morphologically identical edges. Therefore far greater morphological variability is possible between artefacts, without causing compromises in performance, than has been anticipated by previous discussions of artefact function. These results necessarily impose interpretive difficulties on typological and organisation of technology models alike, both of which rely on morphological similarities of stone artefacts to signify similarities in performance and function.

For wear analyses, these implications are further compounded by existing relationships between artefact form and the appearance of wear. The relationship between edge morphology and scar patterning, coupled with the ability for the same function to be performed by a range of different morphologies, means that different morphologies may result in different patterns of use scarring but performs to the same level. That is, the same function may be evidenced both by different morphologies and by different wear patterns but represent equal performance levels within a single assemblage. These results suggest that, in some cases, rather than representing different functions and activities at a site, morphological variability
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may represent a series of tools performing the same functions at different stages of reduction with each manifesting wear differently in accordance with its new morphology. At present the problems identified here for wear analyses are insurmountable, with no way of differentiating between use or contact material on the basis of scar patterning. In their current state, wear analyses seem to be incapable of dealing with the complexity in assemblage variability and functional identification that has been demonstrated to exist.

Representing the primary means by which all models of technology can be tested, problems associated with the inability of wear analyses to identify artefact function necessarily extend to the testing of all interpretive models which relate implement, or edge morphology, with use. Further research into the mechanisms responsible for the development of wear, and the circumstances under which they occur, must therefore be considered essential to all future research investigating artefact function.

CONCLUSIONS AND FUTURE RESEARCH

The research presented in this thesis has identified several crucial and widespread flaws in existing approaches to the interpretation of stone artefact function, with one of its most important outcomes being the recognition that the current assumptions dictating investigations into artefact function are inadequate for explaining the complex and dynamic relationships between variables contributing to artefact function. The extent to which these results have been shown to contradict previous ideas relating artefact form with function indicates that many of the processes and mechanisms acting upon prehistoric stone artefact manufacture and use remain misunderstood.

Direct correlations between form and function have not served the discipline well and indicate a strong need to reconceptualise how archaeologists view stone tools. The development of new models and approaches which embrace the new dynamism recognised to characterise tool use and the processes involved is imperative to improving our understanding of prehistoric hunter-gatherer subsistence across the globe.

Extensive work in the fields of use-wear and the identification of performance characteristics, will be crucial to achieving this goal, facilitating the accurate recognition and differentiation of relevant technological strategies in the archaeological record. While clarifying the complexity of the interactions contributing to the development of wear and performance of functional edges appears daunting, the existence of clear and consistent patterns in the interactions between variables should simplify this search to some extent.
Reassessments of the interpretive value of other forms of wear such as polish and striations would also allow greater clarification of the interpretive state of wear analyses and is intended to be investigated in future work. In addition, the relevance of performance characteristics developed on unretouched edges to models relating form to processes of maintenance and use, or to the function of retouched morphologies is dependent upon the contribution retouch makes to performance. It may be that the effect of retouch on performance is purely to change the morphology of the working edge. Conversely, retouch may contribute to performance by introducing an additional variable to the equation. If retouched edges are shown to perform differently to unretouched edges, then retouch must also be tested as an independent variable and its effects on performance quantified.

The preliminary nature of my analyses means that they have raised many more questions than they have answered, revealing the need for a much greater understanding of the effects of all other aspects of performance on a much wider range of materials and actions as well as retouch. Until such data can be generated, to allow these models to be independently tested, and their effects on morphology qualified, it remains difficult for them to contribute greatly to our understanding of artefact function within broader behavioral systems. The potential for these models to contribute to a more dynamic and broader understanding of artefact manufacture and use than is currently possible should, however, make the collection of necessary data a priority for all lithics analysts.

While considerable work in this area remains to be done, the relative success of these results in exploring some of the more synthetic concepts upon which organisation of technology models are based indicates that it is possible to strengthen and empower these interpretive models through further experimentation. Models of the organisation of technology offer innovative and exciting directions for understanding technology in prehistoric hunter-gatherer subsistence; interpreting the structure of tool use as a dynamic and interactive system. As such, the results presented in this thesis echo recent discoveries by key figures in lithics analysis (e.g. Bamforth 1985, 1986, 1990, 1991b; Bamforth and Bleed 1997; Bleed 1986, 1996, 1997, 2001, 2002; Bleed and Bleed 1987; Shott 986, 1989, 1990, 1996b; Kuhn 1994, 1995). Where their research has focused on a macro scale, on complexities and dynamism in tool use detected in technological systems, this study has investigated similar concepts on the micro scale of the function and performance of individual artefacts and edges. As such, while the research presented in this thesis is the first of what is hoped will be many investigations of its kind, it complements these pioneering studies and contributes to a much larger body of theory relating the
manufacture, and use, of stone artefacts to a broader understanding of prehistoric hunter-gatherer behaviour.
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