3. Procedures for Lithic Analysis

Understanding and depicting all aspects of a technological system should properly begin with the methods of manufacture themselves. Perhaps the best way to examine the manufacturing process is to understand the various procedures and strategies knappers employed to gain control over the material being worked and determine their frequency in archaeological assemblages. From this we may determine their significance in relation to other features of the assemblage (such as the geographic location of the assemblage relative to the occurrence of raw materials, the type and quality of raw materials, etc.). By briefly reviewing the methods of stone fracture and its many intertwined variables and problems, a list of important technological features and their likely strategic significance can be generated. These can be later used to reconstruct the manufacturing system, explore changes in raw material useage and provisioning strategies. I will then detail methods that are useful for understanding, depicting and measuring stone artefact reduction, as this will form the basis for many of the analyses presented later in this monograph.

Stone Fracture, Knapping Strategies and Morphological Attributes

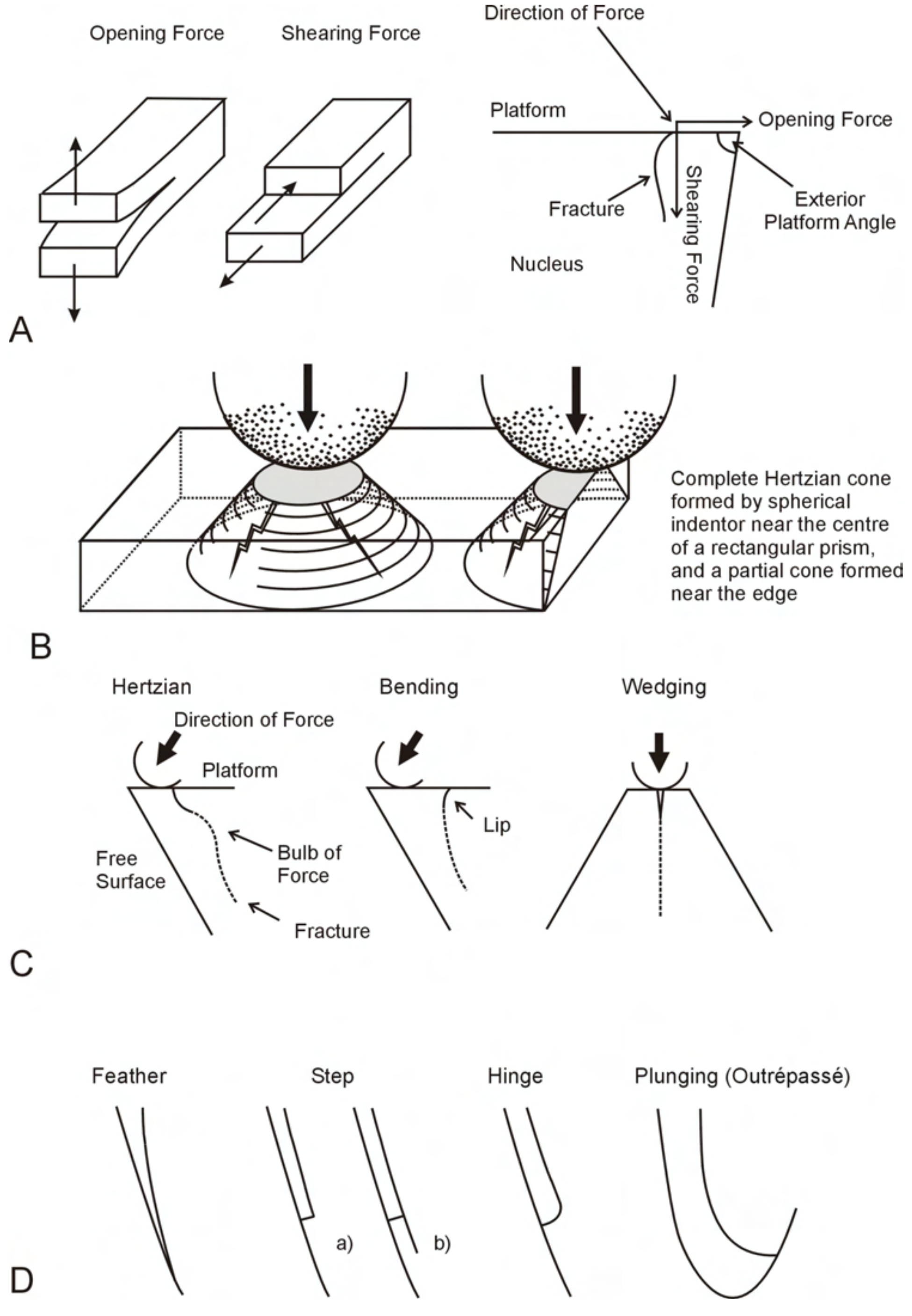
The process of fracture propagation that underlies flaked stone artefact manufacture is complex, and the effects of various core morphologies on the fracture path are not well understood. Yet it is the fracture path that ultimately determines the morphology of flakes and cores, and archaeologists have therefore begun to try and understand this process and the means by which people may alter and control it. Without delving too far into the details, it is possible to briefly describe some of the main principles and the most common fracture features that result.

In most forms of flaking, force is directed into the *platform* (i.e. any surface receiving force) of a nucleus with an indentor (any object imparting force to a nucleus) using one of three techniques: striking the nucleus at high velocity with either a hard indentor such as a hammerstone (hard hammer percussion) or a soft indentor such as a piece of wood, bone or antler (soft hammer percussion), slowly applying pressure through a process called *dynamic loading* (pressure flaking), striking a positioned punch (indirect percussion), or applying compressive force by placing the nucleus on an anvil and striking it from above (bipolar technique) (Cotterell and Kamminga 1987; Kooyman 2000).

Skilled flintknappers observe that in most flaking force is directed into the nucleus using both an inward and outward motion (Crabtree 1972; Whittaker 1994), creating both 'opening' and 'shearing' stresses in the nucleus (Figure 3.1a) (Macgregor 2001). Fracture occurs when stresses within the nucleus reach a critical threshold and break the molecular bonds holding the nucleus together.

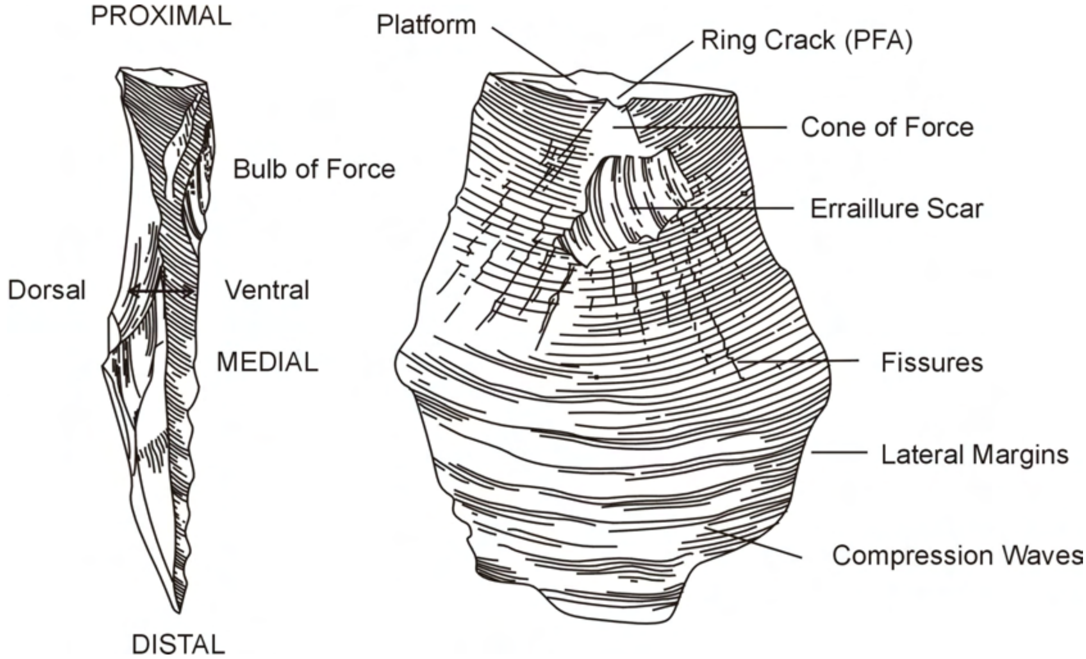
The most common form of fracture is known as *conchoidal fracture*, which begins from pre-existing flaws in the surface of the nucleus close to the point of impact and creates what is known as a *Hertzian cone*, as illustrated in Figure 3.1b. The Hertzian cone propagates in a circle around the contact area and expands down into the nucleus in a cone shape at an angle partly dependant on the angle of applied force. If the nucleus is struck close to the edge, only a partial cone will be visible on the flake (Figure 3.1b). Whether or not a fracture will continue to propagate through the core once a cone is formed (i.e. and not just leave an incipient cone in the nucleus), depends on whether the force of the blow is sufficient to accelerate and overcome the inertia of the material that is to be removed. Once fracture is initiated, a number of counteracting stresses created by the magnitude and direction of force (tensile, bending and compressive stresses) will influence the path it then takes through the core. In conchoidal fracture, the path will typically first head into the core before diving back toward the free face, creating the *bulb of force*, and then stabilizing on a path that is more or less parallel to the free surface (Macgregor 2001).

Figure 3.1. Types and features of fracture initiation and termination (after Andrefsky 1998; Cotterell and Kamminga 1987). A: fracture variables, B: formation of a hertzian cone, C: fracture initiations, and D: fracture terminations.



Conchoidal flakes (i.e. those with Hertzian initiations) often retain a ring crack at the *point of force application* (PFA), and an *eraillure scar* just below the point of percussion on the bulb of force (Figure 3.2). Undulations in the fracture path also often leave *compression waves* on the ventral surface of flakes. Fissures radiating out from the point of percussion are also often found on the ventral surfaces of flakes, but are most often seen on fine grained materials.

Figure 3.2. Fracture features often found on the ventral and dorsal faces of a conchoidal flake (reproduction is by courtesy of the Trustees of the British Museum).



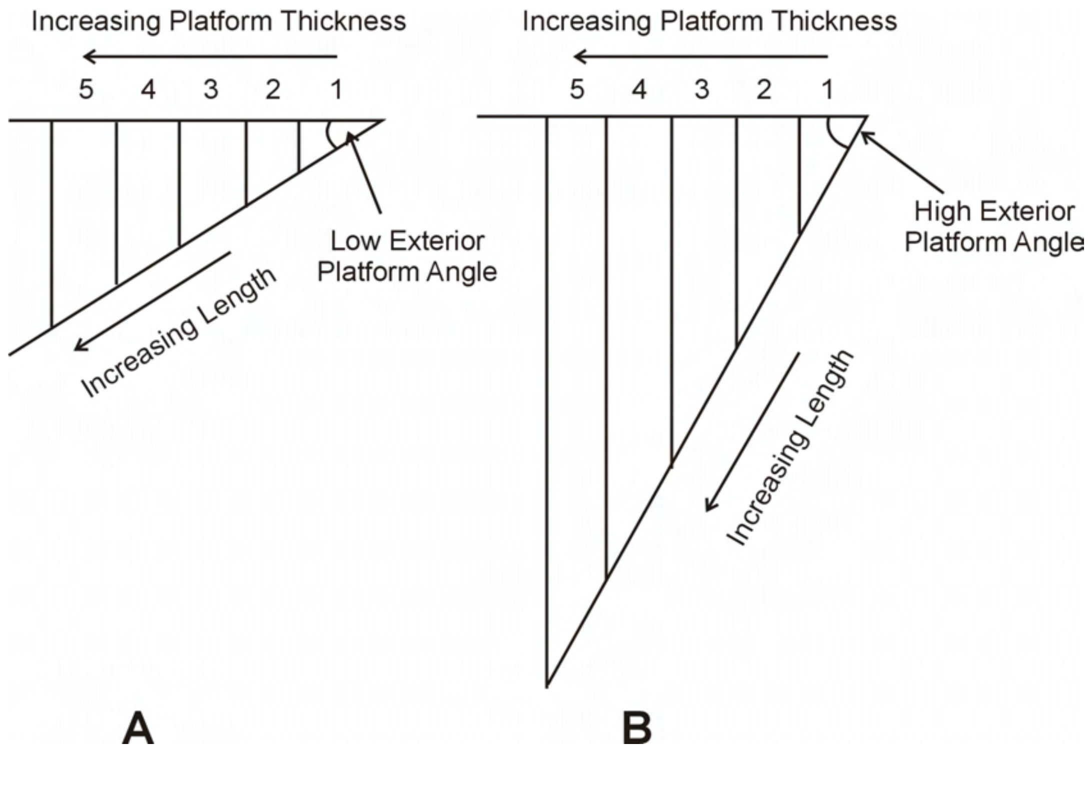
Force eventually exits the nucleus either gradually and at a low angle, creating a *feather termination*, or more rapidly and at around 90 degrees, creating a *step* or *hinge termination* (Figure 3.1d). Not all fractures follow this path, however, and the fracture path sometimes travels away from the free surface and exits on the other side of the nucleus, creating a *plunging* or *outrépassé termination* (Figure 3.1d). Pelcin's (1997c:1111) controlled experiments have shown that when all other variables are held constant, increasing platform thickness will produce regular changes in termination type from feather through to hinge terminations, as the force becomes insufficient to run the length of the free face. The direction of force is also often implicated as a determinant of either hinge or step terminations, but this proposition has not been tested under controlled circumstances. Others have suggested that thick platforms and inward-directed force are more likely to produce outrépassé terminations given sufficient force to initiate a fracture (Crabtree 1968; Faulkner 1972:110-115; Hiscock 1988; Phagan 1985:237, 243).

Less commonly, fracture will initiate behind the point of percussion, creating a *bending initiation*, which dives rapidly toward the free face without forming a Hertzian cone, and leaves a pronounced 'lip' on the ventral edge of the platform (Figure 3.1c). Bending initiations are most commonly formed on nuclei with low angled platforms and have a fracture surface that often resembles a diffuse bulb, even though no bulb is present (Cotterell and Kamminga 1987:689). Although it has long been thought that bending initiations are typically produced by soft hammer and pressure flaking, Pelcin (1997c:1111) found that bending initiations were repeatedly created on cores with low platform angles when blows were placed relatively far in from the edge, suggesting that their frequent association with soft hammer and pressure flaking is more likely a factor of the common use of these techniques in knapping cores with low platform angles (e.g. bifaces) than it is of either force or indentor type (see also Patterson and Sollberger 1978). Pelcin (1997b) was also able to show that soft hammer flakes were on average longer and thinner than hard hammer flakes, and that this technique was therefore better suited to bifacial thinning than hard hammer percussion. Hence the association between soft hammer/pressure and bending initiations is likely to be coincidental rather than causal.

Compression fractures created by bidirectional forces produce a *wedging* initiation that results in flattish fracture surfaces without a bulb of force (Figure 3.1c) (Cotterell and Kamminga 1987). Because compression fractures are typically initiated by particles driven into existing percussion cracks, flakes created through this process often exhibit battered or crushed platforms with cascading step scars on the platform edge (Cotterell and Kamminga 1987). Bipolar cores and flakes that have been rested on an anvil most commonly display this form of initiation. Because the anvil on which the nucleus is supported can also act like a hammerstone, bipolar flakes can at times exhibit platform and initiation features at both ends, such as crushing, dual bulbs of force and bi-directional compression waves. When nuclei are stabilised on an anvil, problems of inertia – or the probability of a blow moving the core rather than detaching a flake - can be dramatically reduced. This technique is therefore ideally suited to working very small cores (Hiscock 1982b, 1988:18).

Recent controlled fracture experiments have revealed that the closer the Hertzian cone is to the edge of the nucleus, and the lower the external platform angle (EPA), the less material needs to be accelerated away from the core, and hence the less force will be required to initiate a fracture (Dibble and Pelcin 1995; Dibble and Whittaker 1981; Macgregor 2001:46; Pelcin 1997a, b, c; Speth 1974, 1975, 1981). The more these variables are reduced, however, the smaller also the resulting flake will be. This relationship is illustrated in Figure 3.3a, and can be seen to be a simple result of changing core geometry. Alternatively, increasing platform angle and striking further from the edge requires greater force input to initiate a fracture, but also results in larger flakes (Figure 3.3b). Increasing force input by too much can result in longitudinal splitting of the flake or crushing of the platform edge. At some point, increasing EPA and/or platform angle will reach a threshold at which the amount of force required to detach a flake will exceed the inertia of the nucleus itself, and will result in moving the nucleus rather than detaching a flake (Phagan 1985:247). At this point, force requirements can be reduced by decreasing EPA, platform thickness or both, or by stabilising the core on an anvil.

Figure 3.3. The effects of increasing or decreasing platform angle and platform thickness on flake size.



Most recently, Macgregor's (2001, 2005) experiments have demonstrated that removing some of the mass of the free face (such as might occur through overhang removal for instance) allows a blow to be placed further from the platform edge (given the same amount of force) than would have been possible were it not removed (thereby detaching a larger flake). Furthermore, Macgregor found that the morphology of the free face directly affected the morphology of the resulting flakes. His experiments demonstrated that features such as large pre-existing step or hinge terminations on the free face will decrease the viable platform area at which fractures can be successfully initiated. In the case of pre-existing step and hinge fractures, more force and the placement of blows further into the nucleus was required to successfully remove a pre-existing step or hinge termination without adding another one. It can be expected then that as more step and hinge terminations build up on the dorsal surface it will become increasingly difficult to remove them from the free face, as the viable platform area will become too small and the amount of force required too excessive to strike off a flake without shattering the platform, adding new step terminations, splitting the flake longitudinally, creating an outrépassé termination, or failing to initiate a flake altogether. A study by Pelcin (1997a) also demonstrated that varying the shape of the free face morphology affected the dimensions of the resulting flakes by changing the distribution of mass over the resulting flake. Flat-faced cores with no longitudinal ridges (*arrises*) on the free face produced shorter flakes with expanding margins and bigger bulbs of force, while cores with two longitudinal ridges on the face produced flakes that were longer and more parallel-sided with smaller bulbs of force. Pelcin's findings confirm the observations of flintknappers that setting up ridges running the length of the core face aids the production of longer, thinner, and more parallel-sided flakes (Crabtree 1972:31; Whittaker 1994:106).

The study of fracture mechanics has progressed a great deal in a very short time, but many questions are still unanswered, such as the effects of different raw materials, hammerstone size and velocity, direction of force and more complex core morphologies on the fracture path. It is also uncertain how well (or at least how directly) principles distilled from controlled experiments can be applied to archaeological assemblages. Nevertheless, studies of fracture mechanics continue to dispel myths about the causes of certain fracture features, and serve as a source of hypotheses about why particular knapping strategies might have been applied in the past. As these processes operate today in exactly the same way they did in antiquity, they offer a rare and invaluable link between the 'static' artefacts found in the archaeological record and the 'dynamics' of past human behaviour.

We can therefore identify a number of trade-offs between the interdependent variables of platform size, platform angle, core inertia, force input and nucleus morphology that knappers must manipulate to gain control over the fracture path and to extend the reduction of raw materials. A large number of strategies were employed in the past to modify force variables, rectify problematic morphologies and prevent prematurely damaging the nucleus.[1] These focus on variables that are under the direct control of the knapper and tend to be visible archaeologically. In exploring the type and frequency of various fracture features and deducing the significance of the reduction techniques employed in the past, the analyst must be aware of the pre-eminent role that fracture mechanics plays in shaping each individual artefact. Much of the behaviour associated with working stone likely revolves around gaining and maintaining control over the fracture path so as to remove flakes of desirable shape and size while avoiding premature damage to the nucleus. Studying the interactive effects of core morphology and force variables, and the point in the reduction sequence at which certain techniques are employed (such as platform preparation, core rotation, etc) therefore allows us to piece together the strategies people used to gain control over the fracture process, to shape cores and flakes in different ways, to recover from certain problems, and the point at which cores were deemed to contain no further reduction potential for the task at hand.

Capturing the complexity of the reduction process can be achieved by recording many variables on cores and flakes that reflect these processes and decisions. These include:

[1] see Table 1 of Clarkson and O'Connor 2005 for a list of common strategies for overcoming problems in core geometry and inertia.

- the number of scars found on cores as a measure of overall reduction intensity as well as the success in maintaining suitable core geometry
- the number of platforms on cores as a measure of attempts to overcome problems in the geometry of cores and prolong reduction
- the nature, complexity and circumference of the platform surface that was flaked as measures of the constriction of available platform area
- platform angles and size as a measure of likely force inputs and platform constriction
- the presence of overhang removal and faceting as an indication of the desire to strengthen platforms, increase the size of flakes and control platform angles
- the types of terminations found on cores and flakes as an indication of how successfully force variables and core geometry were controlled
- rates of longitudinal splitting as a measure of force control
- the type of fracture initiations as a rough guide to the techniques of force application used
- the size and shape of the cores as an indication of reduction thresholds and problems in core geometry that led to strategy switching or discard
- the shape and size of flakes as a measure of consistency in the products of flaking

Many of these attributes are used to infer changing core reduction practices over time in the study region, and the results will be presented later in this monograph.

Understanding the combination of reduction techniques and strategies employed in space and time is also vital to understanding the technological solutions people adopted to changing foraging and land use conditions. Documenting changes in the frequency of various alternative reduction strategies also requires that we have a system for placing these techniques in their proper position within the reduction sequence. This means finding ways of time-ordering the various manufacturing products produced over the reduction sequence. Such a system can be established by hypothesising the sorts of changes in core and flake morphology that should accompany continued reduction, and using combinations of these attributes to place each specimen into an appropriate time-slice within the reduction continuum. The following sections explore ways that this can be achieved for cores, flakes and retouched flakes.

Depicting the Core and Flake Reduction Process

As stone-working is a reductive technology, the measurement of the degree to which this process has progressed often forms the basis of many modern analyses. Quantifying extent of reduction allows estimations to be made of the amount of time and energy invested in the production of an artefact, the level of departure of the observed form from its original form, the amount of material likely to have been created as a product of the process, the position in the sequence at which changes in manufacturing strategies took place, and their likely effects on artefact morphology. At a higher interpretive level, many archaeologists see measures of reduction as critical to testing of behavioural models that hypothesize the place of stone artefacts in broader systems of time budgeting and land use. Consequently, measures of reduction have come to be associated, at least implicitly, with discussions of risk (Bamforth 1986; Bamforth and Bleed 1997; Myers 1989; Torrence 1989), cost (Bleed 1996), and efficiency (Jeske 1992) in past technological systems. These discussions build on the assumption that the differential distribution of sequential steps and stages through space and time will reflect aspects of planning, land use, ecology and settlement and subsistence patterns effecting people's daily lives (Kuhn 1995; Nelson 1991). Measures of reduction are consequently fast becoming a central component of lithic analysis, and underlie an important component of technological analysis – reduction sequence models.

Measures of reduction are also a particularly important means of detecting the sorts of changes in technological organisation and toolkit design outlined in the previous chapter. It was argued for instance that foragers may choose to extend the life of their toolkits when the chances of being caught without tools or tool making potential creates subsistence risk, or when greater initial investment requires a longer use-life to recoup the costs of manufacture. One way that this may be achieved is to

take the reduction of stone into later stages, by rotating cores more heavily, adopting stone-working strategies that prolong reduction and provide greater utility per unit weight of stone removed, and by resharpening and recycling tools rather than discarding them and making new ones.

Reduction Sequence Models

Sequence models are theoretical constructs that attempt to time-order phenomena by positioning them at points along a temporal continuum. In lithic studies, sequence models are typically used to determine the ordering of technical actions and outcomes involved in the reduction of stone materials. Models of this sort often use measures of reduction intensity to track changes in artefact morphology throughout the reduction process, enabling the identification of common forms and the use of particular techniques at different points along the way. Sequence models have proved particularly useful in understanding and graphically depicting the various steps and transformations that characterise a wide range of lithic reduction strategies across space and time. While all reduction events form a continuum, reduction sequence models also allow us to envisage the process of reduction as either continuous in its spatio-temporal or physical arrangement (that is, the entire process takes place in one place and in a continuous sequence, or forms are gradually reduced through use and resharpening), or staged, such that various components of the process (such as procurement, initial shaping, resharpening, recycling and discard) all take place in different places at different times, with one kind of action often taking place in anticipation of another kind of future action (Bleed 2002). The notion of staging is also useful in conceptualising the way implements might be designed and transformed, with toolmakers sometimes making decisions to radically change the way a piece was to be used and shaped.

As Bleed (2001) and Dibble (1995) have pointed out, not all sequence models share the same research goals or even the same philosophical underpinning. Some approaches promote a normative view of reduction that focuses on revealing the predetermined stages prehistoric artisans went through to produce specific 'end-products' in accordance with a mental template – a charge Dibble (1995), Bleed (2001) and Shott (2003) have levelled at the *chaîne opératoire* school. Others seek to draw out the contingent nature of technological responses to changing options and circumstances by examining the nature and frequency of artefacts at different stages of reduction across space and time. This view sees production strategies as rarely involving a simple linear sequence of activities with predictable results, but rather an "expanding array of alternatives defined by intervening options and outcomes" (Bleed 1991:20). Others still have used sequence models to expose the non-reality of essentialist typologies by demonstrating the existence of underlying morphological continuums (Clarkson 2002a, 2005; Hiscock and Attenbrow 2002, 2003; Morrow 1997).

Bleed (2001) sees different approaches to sequence modelling as falling into one of two categories, which he calls 'teleological' and 'evolutionary'. Teleological models treat sequences as "a set of internally determined actions that follow one from another and lead to a predetermined goal", whereas evolutionary models describe results that are produced "by selected interaction between conditions and variables" (Bleed 2001:121). Evolutionary models therefore attempt to express the variation within a particular reduction system as much as the central tendency. Thus, while reduction sequences provide a useful means of ordering different assemblage components into reduction stages, they should not be taken to demonstrate normative modes of behaviour or the existence of 'mental templates' for stone artefact production.

The following sections identify ways in which reduction sequences can be modelled for cores, flakes and retouched implements. As variation in reduction pathways is of as much interest as central tendency, techniques for depicting variation in these reduction processes are also considered.

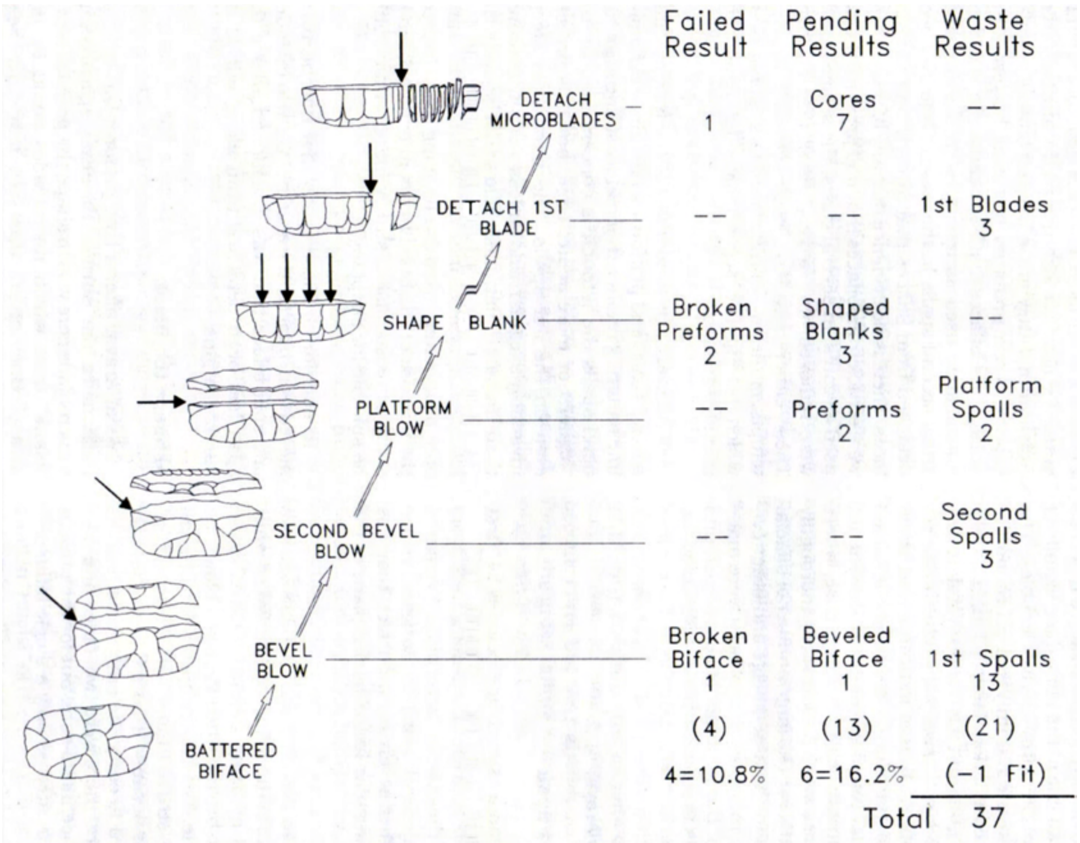
Modelling Core Reduction

Both fracture mechanics and basic engineering principles would suggest that striking more and more mass from a core will affect its size and geometry, which will have direct consequences for the nature of force input, the viability of different reduction strategies and the size and morphology of the flakes produced over the sequence.

We can speculate for instance that the gradual reduction of cores will result in more flake scars and less cortex, that continued use of a platform will result in a decrease in platform size, and that as more mass is struck from a core the size of the core and resulting flakes might also decrease. If cores are rotated during this process to create fresh platforms once old ones become damaged or unproductive, they should begin to preserve signs of former flaking on the platform surfaces as well as indications of the existence of old platforms. Morphological changes in core form and in the strategies used to prolong core reduction can be tracked as the number of rotations increases.

Another way to show variation in the reduction pathways and use of different techniques is to assign frequencies to various stages of sequential or dendritic reduction flow charts, or what Bleed (1991, 2001, 2002) calls 'event trees', as shown in Figure 3.4. Event trees summarize overall production systems by identifying their steps (events) and showing how they relate to one another, thereby helping clarify the dynamic relationships between static and formally diverse remains (Bleed 1996). Event trees accommodate the possibility that reduction sequences may not form a straight-line, and also add the potential for quantification of the level of variation in the system by attaching frequencies to various steps. They may also help determine the probability of failure associated with each step by examining the proportions of failed pieces belonging to each stage (Bleed 1996).

Figure 3.4. An 'event tree' describing the sequence of manufacturing actions and the frequencies attached to each conceptual stage of the process. Reproduced from Bleed (2001).



Modelling Flake Reduction

Lithic analysts have devised numerous means of assigning flakes from archaeological assemblages into reduction stages, and thereby measuring reduction intensity. This has typically involved experimental production and description of debitage from each stage of a hypothesized reduction sequence, or resulting from different reduction techniques, in the hope of comparing the characteristics of the experimental debitage (such as platform and dorsal attributes, weight or breakage patterns) to archaeological materials such that each artefact in an assemblage can be assigned its likely position in the reduction sequence or its likely manufacturing technique (e.g. Ahler 1989; Austin 1997; Bradbury

and Carr 1999; e.g. Bradley 1975; Flenniken 1981; Newcomer 1971; Odell 1989; Patterson 1982, 1990; Patterson and Sollberger 1978; Shott 1996; Stahle and Dunn 1984; Steffen *et al*. 1998; Baulmer and Downum 1989; Bradbury 1998; Bradbury and Carr 1999; Morrow 1997; Prentiss 1998; Prentiss and Romanski 1989; Root 1997; Shott 1994; Sullivan and Rozen 1985). Unfortunately, these analyses generally fail to demonstrate that the stages followed experimentally were those followed in the creation of the archaeological assemblage (as might be demonstrated through refitting for example) (Hiscock 1988; Newcomer 1975:98; Schindler *et al*. 1984), or that the debitage resulting from each step can be reliably identified in archaeological contexts.

To avoid this analogical approach, flake reduction is instead approached in terms of simple and universal changes in flake morphology that are deduced from the analysis of changing core morphology, as reflected in dorsal and platform scar morphology. This type of analysis is called *diacritical analysis* (Sellet 1993), and aids in the construction of hypothetical reduction models.

The reduction process can be modelled by examining stages in flake scar superimposition on the platform and dorsal surfaces of flakes and the stages of decortication present. For example, the first flakes struck from cores are expected to preserve cortex on all exterior surfaces. Middle stages will preserve scars from prior removals on the dorsal surface, less cortex, and may begin to show scarring on the platform that results from rotation of the core and the use of an old core face as a platform once flaking resumes. Late stage flakes should show no cortex, complex platform morphologies and a number of other features such as greater elongation, more dorsal scarring, higher incidence of non-feather terminations, etc.

Modelling Retouched Flake Reduction

Retouched flakes are most commonly the subject of detailed lithic analysis, but until recently few techniques existed to measure the amount of time and labour invested in their production. A number of procedures have been proposed and tested in recent years that offer a means of measuring reduction for different forms of retouching (Clarkson 2002b; Hiscock and Clarkson 2005a, b; Kuhn 1990).

Elsewhere I have published a procedure for assessing scar abundance using estimation of retouch scar coverage (Clarkson 2002b). This ‘Index of Invasiveness’ calculates intensity of retouch by estimating the extent of retouching around the perimeter of a flake as well as the degree to which it encroaches onto the dorsal and ventral surfaces. The index is calculated by conceptually dividing an artefact into eight segments on each face. Each segment is then further divided into an inner ‘invasive’ zone, ascribed a score of 1, and an outer ‘marginal’ zone, ascribed a score of 0.5. Scores of 0 (no retouch), 0.5 (marginal) or 1 (invasive) are allocated to each segment according to the maximum encroachment of scars into one or other of these zones (Figure 3.5). The segment scores are then totaled and divided by 16 to give an index between 0 and 1. Experimental evidence for a strong and significant positive relationship between the index and the number of retouch blows and demonstrates the percentage of original weight lost from each specimen that is linear when log transformed (Clarkson 2002b). Little variation is evident in the rates of index increase between raw materials of varying fracture quality. The Index of Invasiveness has the advantage of being fast to calculate and versatile, and is well suited to the measurement of both unifacial and bifacial retouch with minimal inter-observer error (Clarkson 2002b:71).

A limitation of measuring surface coverage of retouch scars is that it is less suited to assemblages in which artefacts exhibit predominantly steep and marginal unifacial retouch, as might commonly occur on backed artefacts or steeply retouched scrapers. For instance, the Index of Invasiveness would not readily increase above 0.25 in such cases, no matter how much reduction takes place. In assemblages with non-invasive marginal retouch, alternative measures of reduction may be more appropriate, such as Kuhn’s index of reduction.

Figure 3.5. The Index of Invasiveness (from Clarkson 2002b).

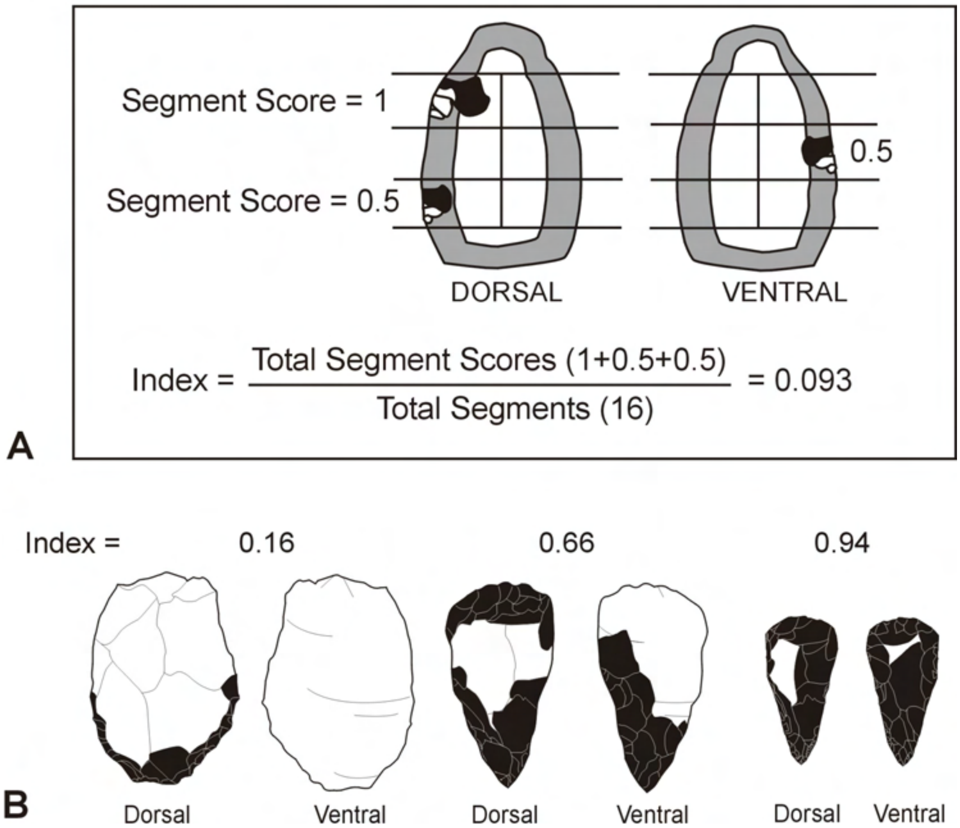
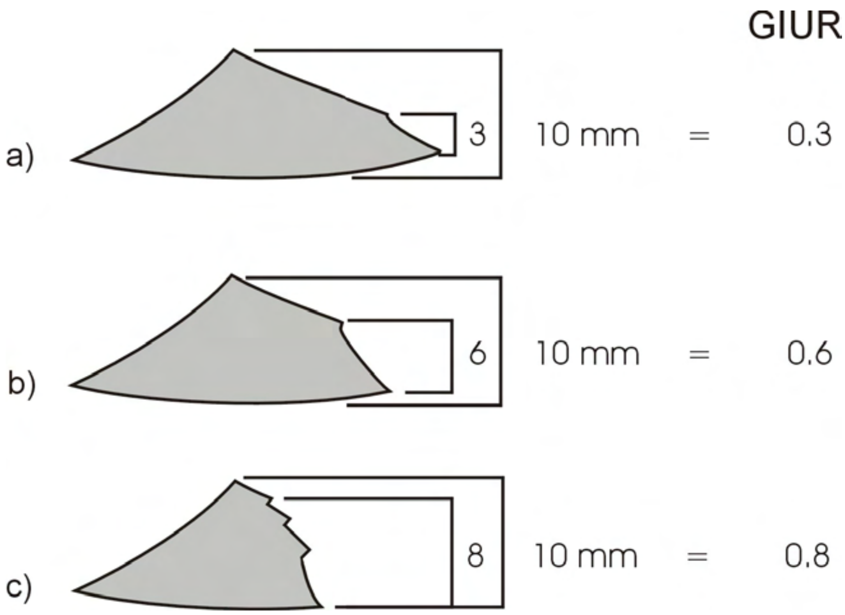


Figure 3.6. The geometric index of unifacial reduction (GIUR).



Kuhn's (1990, 1995) Geometric Index of Unifacial Reduction (GIUR) is a fast and sophisticated quantitative measure of flake margin attrition. The GIUR calculates the ratio between retouch height and flake thickness, expressed as a figure between 0 and 1 (Figure 3.6). Although theoretically sensitive to variation in the cross-sectional shape of flakes (and particularly 'flat flakes' – see Dibble [1995]), recent independent experimental testing has revealed that Kuhn's Index is a robust and reliable measure of dorsal unifacial reduction that is linear when the percentage of original weight lost from specimens is log transformed (Hiscock and Clarkson 2005a, b). The GIUR also out-performs many other measures of unifacial reduction against which it has been compared.

In this study, the Index of Invasiveness will be measured on all retouched flakes (i.e. those with unifacial and bifacial retouch), while the GIUR will also be used to measure unifacial dorsal retouch. Together, these techniques form a powerful and generic means of ordering any retouched specimen into its position within a reduction sequence. Understanding these continuums also allows us to partition variation in meaningful ways and offers us an alternative to traditional classifications that often employed analytical units that masked and obscured the underlying reduction processes creating much of the observed variation in retouched flake characteristics.

Like core reduction sequences, understanding the system of retouching and implement production helps us test predictions about toolkit design and technological investment decisions. These include the overall degree to which different forms are reduced as a reflection of increased use-life, the suitability of different forms to multiple resharpening events as might be predicted for maintainable tools, the level of variation in implement form as a reflection of transportability, and likelihood of use in composite technologies.

Analysing Artefact Form

Reduction sequences provide a fundamental means of describing the various reduction pathways through which artefacts move in response to the contingencies of functional demand and raw material availability. They also help determine the temporal ordering of technical actions and changes to the form of artefacts. Also of great interest in exploring technological variation and in testing predictions of provisioning models, however, is documenting changes in the morphological properties of artefacts (often called formal variation) that take place as reduction continues. For retouched flakes this might involve changes in such attributes as edge curvature, edge shape, edge angle, the location of retouch and the frequency of notching. For cores it might involve changes in the shape and size, the numbers of scars and core rotations. This section therefore describes a number of techniques used to document formal variation in stone artefacts as reduction continues.

Measures of Core Size and Shape

The principle measures of core size and shape used in this study involve changes to the shape of the core face and platform, often plotted in relation to measures of size such as weight or length. The shape of the core can also be calculated as the ratio between platform width and distal width, or length:width. Coupled with a knowledge of core reduction technique (i.e. bipolar reduction vs. single platform core reduction), these measures can be extremely useful tools for exploring the effects of changing morphology on the size and shape of flakes produced at each stage of reduction as well as inferring which techniques best suite certain core shapes and the production of certain implement forms.

Measures of Flake Size and Shape

Flake size can be measured as surface area (length x width), by weight, or by any other axial measure such as length, thickness, width or maximum dimension. Shape can also be measured in a number of ways. For instance, the expansion or contraction of the lateral margins can be calculated as the *marginal angle*, or the angle of convergence of the lateral margins toward the distal margin. This is calculated using the following formula:

$$\tan\frac{\theta}{2} = \frac{\left(\dfrac{\text{proximal width - distal width}}{2}\right)}{\text{length}}$$

$$\text{And hence angle of the lateral margins } (\theta) = 2\tan^{-1}\frac{\text{proximal width - distal width}}{2 \text{ x length}}$$

The measurement procedure for this index is shown in Figure 3.7a. Expanding margins return negative angles, while margins that contract along their length have positive angles. Parallel sided artefacts have an angle of 0. Other ways of measuring flake shape are also possible, such as the angle between the proximal end and medial width, the angle between the medial width and the distal end, or some other combination of these.

Shape can also be measured for retouched edges using a number of indices. One is the angle of the retouched edge, and this can be calculated as the mean of several edge angle measurements taken at regular intervals along the retouched edge (3 intervals are used here). Another is the index of edge curvature, measured by dividing the maximum diameter of retouch by the total depth of retouch (Figure 3.7b) (Clarkson 2002a; Hiscock and Attenbrow 2002, 2003). Negative results indicate concave edges, while positive ones indicate convex edges. Curvature can be used to measure overall edge shape as well as more minor features, such as concavities and notches.

Blank Selection

Archaeologists are often interested in the process of blank selection, or the selection of a sub-set of flakes for further use, retouching and/or transport away from the site. Blank selection is of interest as it has the potential to inform us about design considerations (such as tool performance, reliability/maintainability, suitability to prehension and hafting and multifunctionality), a range of environmental and cultural constraints (functional, material, technological, socioeconomic and ideological) (Hayden *et al*. 1996). It can also tell us about the level of standardisation in the production system, both in terms of overall flake production and selection from the larger pool of flake variation. The approach adopted here to determining the relationship of selected blanks to the overall pool of variation is to plot flakes at early stages of retouching against the larger pool of variation in size and shape. Graphical techniques will be used, as well as statistical measures of variance and central tendency to compare and contrast the size, shape, and standardisation of blanks.

Conclusion

This chapter has drawn together various approaches to the description of assemblage variation that are of analytical importance in the analysis of technological change. The review of stone artefact manufacturing strategies and approaches to building reduction sequences serves as the basis from which to explore changes in the organisation and design of lithic technologies in later chapters and to detect broad changes in technological provisioning and land use.

Figure 3.7. Measurement procedures for describing flake shape. A: angle of the lateral margins, and B: curvature of the retouched edge.