Australian point and core reduction viewed through refitting

Peter Hiscock

Abstract

Refitting of knapping floors in northern Australia is used to analyse the production technology employed during the mid- to late-Holocene. Examination of refits at quarries is the basis of a study not only of the general sequence of reduction but also the solutions that knappers apply to solve problems they encounter. A series of refitted knapping floors at increasing distances from quarries reveal the progressive modification of bifacial points and cores as material is transported through the landscape. This case study is employed as an illustration of the value of refitting studies as a means of explicating regional technological and economic patterns. It is argued that future refitting analyses will more powerfully exploit the potential of the technique when quantitative measurements are used to evaluate not only technological trajectories during the reduction process but also the variability that occurs within and between sequences.

Refitting assists archaeologists to develop models of lithic artefact manufacture which describe the entire reduction process rather than merely the end products, that measure variability in knapping rather than only normative images of technology, and which depict the relationships between localities in terms of the regional socio-economic strategies that prevailed in the past. Such models act as powerful interpretative devices and are increasingly being generated by archaeological research. Outstanding examples of refitting being used to construct details of prehistoric technology exist; like Barton's (1992) discussion of the extent, strategy and variation in core reduction at Hengistbury Head. However it rare for all of these elements to be present is a single model. More commonly excellent refitting studies rely on the researcher's unquantified textual descriptions, perhaps aided by photographs or realistic drawings of artefacts, to advance the interpretation of the manufacturing process (eg. Ahler 1992; Arnold 1990; Gilead and Fabian 1990; Lohr 1990; Morrow 1996; Rensink 1990; Schafer 1990; Weiner 1990; Wyckoff 1992). Refitting is not in and of itself an analysis of the technological patterns that exist in a reduction sequence. Refitting orders artefacts into their sequence of production, thereby facilitating measurements of the trends in reduction sequences. By developing modes of quantitative analysis for refitted sequences the potential of conjoining can be more powerfully exploited. For instance, quantitative research can assist in portraying and understanding variation within a technology, thereby moving beyond normative depictions to an image of the complexity and diversity of technological activities. This in turn may enhance our ability to understand assemblage differences within the economic variation that occurs within any region. In this way refitting plays a central role in an ongoing exploration of analytical frameworks that can describe the complexity of knapping by studying characteristics such as error rates, variations of reduction strategies, strategy switching, responses to raw material properties, and so on. This paper provides an example of the value of refitting analyses in the explication of technological variation that occurred with a small region. The example is drawn from Australia and involves an examination of core reduction and point production. A normative view of antipodean implements had at one stage created an image of very simple and uniform technologies (see White 1977), whereas the quantitative study of refitted artefacts has now revealed a varied and complex technological system represented in these Australian assemblages.

POINT AND CORE REDUCTION IN NORTHERN AUSTRALIA

Across northern and central Australia archaeological sites contain unifacial and bifacial points, and large, elongate flakes often called 'leilira', some of which have lateral retouch. The relationship of these artefact forms to each other, and to the processes of initial core reduction, is poorly understood and the subject of current investigation. It is now clear that in many regions unifacial and bifacial points represent morphological and reduction continuums (Hiscock 1994), and that the elongate leilira flakes have many histories: some were traded and used without retouch, some were transformed into points, while some were retouched in other ways (Jones and White 1988:52). Part of this variation may reflect recycling and changes in the role of trading systems (Allen 1994), but much of this variation probably reflects behavioural differences arising from dissimilar local and regional circumstances. Studies of flake production, and of retouching patterns, would illuminate the causes of these archaeological differences, but although Jones and White (1988:62-76) have provided ethnographic descriptions of production, detailed archaeological studies of core reduction and point manufacture in these industries have been minimal (although see the important studies of Clarkson and David 1995; Cundy 1990; Thorley, Warren and Veth 1994).

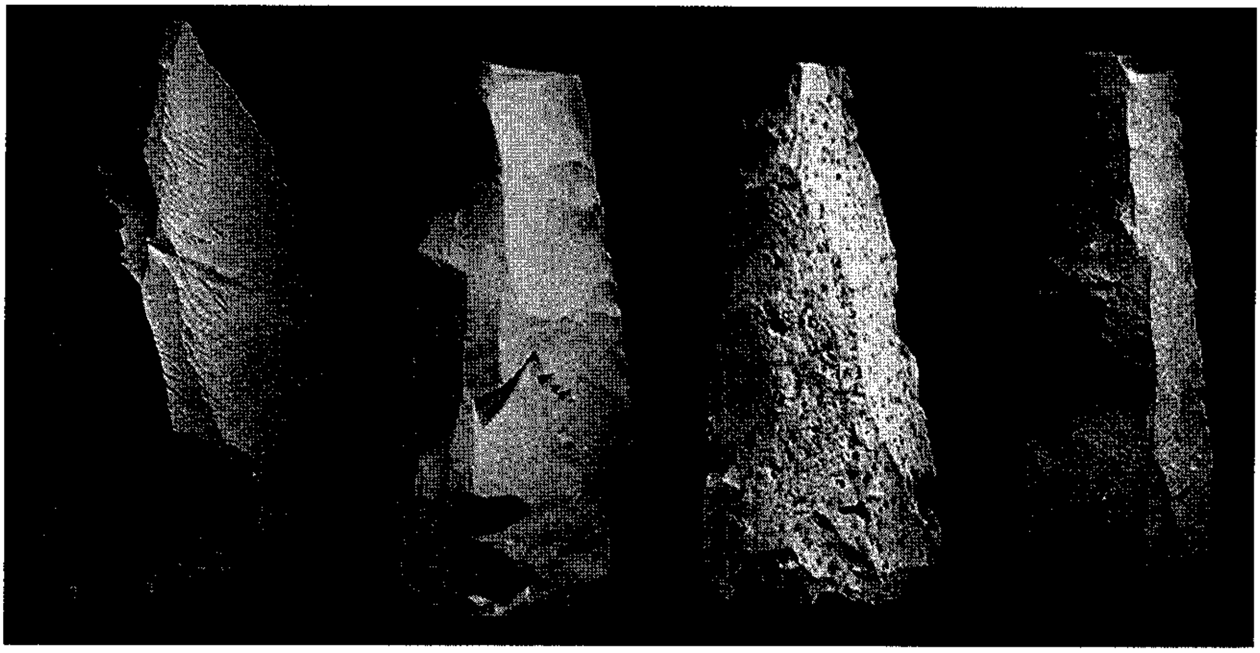

Figure 1 Examples of bifacial points from northern Australia showing progressive reduction from unifacial and unimarginal retouch (left) to bifacial and bimarginal (right).

Studies of reduction processes have a long history in Australia (see Hiscock 1998), but have often been based on technological classifications (e.g. Wright 1972), attribute analyses (eg. Clarkson and David 1995; Lamb 1996), or seriation of artefact size and shape (eg. Hiscock and Attenbrow in press; Hiscock and Veth 1991). Refitting has only intermittently been employed as an aid to interpreting assemblages (eg. Noetling 1908; Hiscock 1993), but has not previously been carried out in investigations of the northern leilira and point assemblages (although Clarkson is currently undertaking such an analysis). In the following pages I outline a conjoining study of Holocene aged sites from the semi-arid plain immediately south of the Gulf of Carpentaria (see Figure 2). These sites yielded a series of refitted knapping floors at increasing distances from quarries, revealing the progressive modification of bifacial points and cores as material is transported through the landscape. Transportation of artefacts across this lateritic plain is readily identified because the only source of flakeable rock for many kilometres is a low ridge of greywacke, bisected by Page Creek, on which a number of quarries are evident.

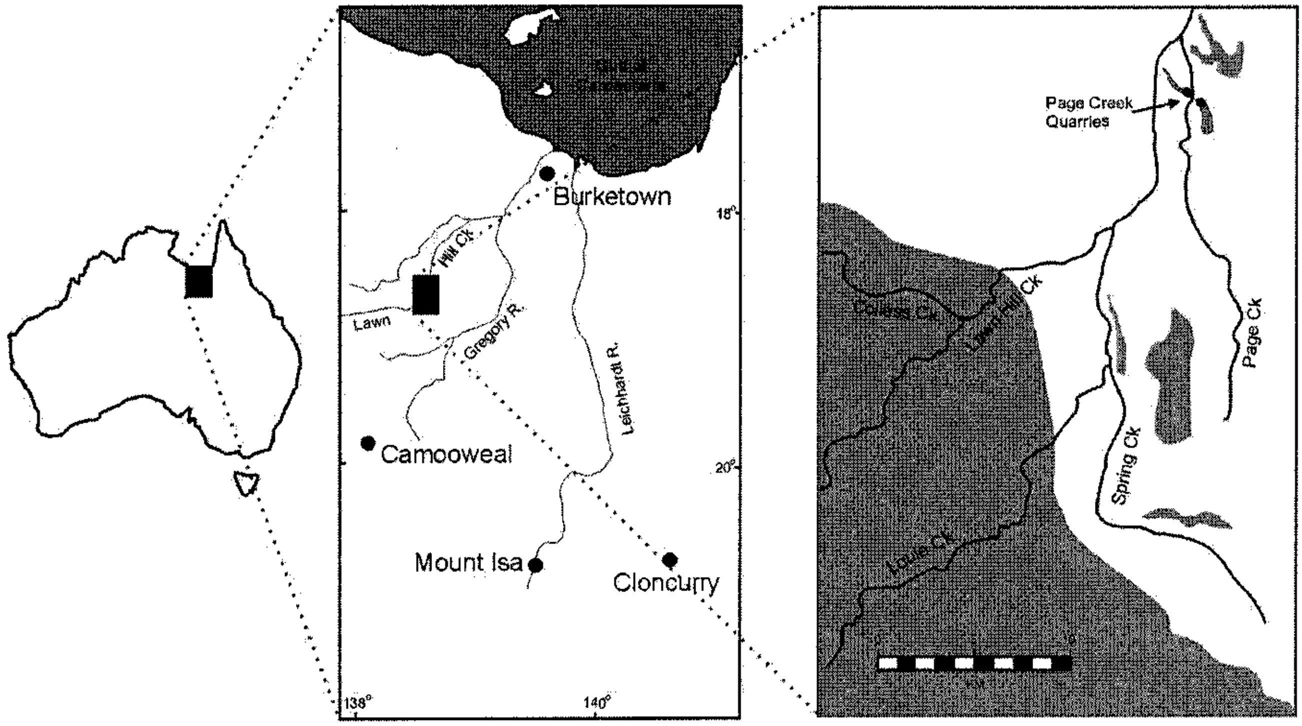

Figure 2. Map showing the location of the Page Creek quarries in northern Australia.

PAGE CREEK QUARRIES

The example that will be used to illustrate the advantages of refitting in investigations of point and core production focuses on the extraction of greywacke from a source on the flood plains surrounding the Gulf of Carpentaria in tropical semi-arid northern Australia (Figure 2). In the area south of Lawn Hill Homestead an extensive, flat flood plain slopes gently to the north and has local relief up to 100 m in the form of hills and mesas. A steep rocky ridge protrudes from the flood plain, and runs roughly west to east for a distance of 3 kilometres. Covered by a thin mantle of siltstone and greywacke cobbles and blocks, the ridge has artefact scatters indicating quarrying where cobbles of suitable quality and form were located. Two quarry localities were recorded on this ridge. Page Creek Quarry 1 has a scatter of artefacts covering an area of 9350 m^2, with artefact densities varying from $0.25/m^2$ to $39/m^2$ and averaging $7/m^2$. A short distance to the east Page Creek Quarry 2 is positioned on the crest and flank of the ridge, as indicated by a scatter of chipped artefacts at low densities, averaging $0.5/m^2$.

The quarried material ranges from greywacke through silty greywacke to tuffaceous siltstone but is here all grouped under the term 'greywacke'. The greywacke is a dark, vivid green-grey or blue-grey with brown or yellow flecks, but the surface of many artefacts has been weathered to a light grey. Cortex is thick, often more than 1 cm, rough and dull, and is generally cream in colour. Thin-section examination reveals that the greywacke consists of angular and subrounded quartz grains, chalcedony grains, and particles of plagioclase in varying proportions. Grain size varies but is generally less than 0.2 mm (see Hiscock 1988 for details).

Physical characteristics of the greywacke at cropping out at Page Creek can be expressed in terms of compressive and tensile strength, and modulus of elasticity. Table 1 provides these characteristics for the greywacke and for the only other frequently used lithic material in the region, a banded chert. In contrast to chert the strength of greywacke is markedly lower, and values for the Modulus of Elasticity are always lower for greywacke than for chert, indicating that greywacke is markedly less stiff than chert. Thus, while less force was required to initiate fractures in greywacke than in chert, the lower elasticity and stiffness of the material made fracture in greywacke less controllable. As a result of the relative inelasticity, platform shattering and step terminations occur frequently on greywacke. The properties of greywacke suit it to the production of large, thick flakes, and the potential use-life of greywacke artefacts is comparatively short, encouraging repeated resharpening.

Table 1
Physical properties of chert and greywacke from Lawn Hill (data from Hiscock 1988)

	Greywacke (N=23)	Chert (N=29)
Tensile strength*	44.5 ± 8.4	76.6 ± 25.6
Compressive strength*	347.5 ± 116.9	1044.8 ± 167.4
Modulus of Elasticity**	47,401.3 ± 6,892.7	58,087.6 ± 1,706.0

* = Newtons per square millimetre   ** = Newtons per millimetre

The greywacke occurs as rounded and subrounded cobbles and boulders and as angular slabs. At Page Creek the cobble size is relatively uniform, averaging 5,337 cm^3 in volume. Specimens examined in thin-section were homogeneous in terms of grain size, but in many cobbles there are also distinct weathered cracks running parallel to the long axis. Greywacke fractures well but flakes struck across these cracks are likely to be truncated.

The antiquity of quarrying and knapping at the Page Creek sites is uncertain. Rockshelter sites less than 30 kilometres to the south contain greywacke artefacts in levels older than 20,000 BP, but the exact source of this material has not been established (Hiscock 1988). Variation in the flaked surface of artefacts, ranging form thickly patinated grey to unpatinated dark rock, suggests that quarrying took place over an extended period perhaps covering the late Pleistocene as well as the Holocene.

REDUCTION AT PAGE CREEK QUARRIES

At Page Creek the cobbles of greywacke were large and rounded, and prehistoric knappers often removed large numbers of flakes in each reduction sequence. The amount of reduction on each cobble can be roughly estimated from the flake:core ratio of 30:1; although interpretation of this ratio is always complicated by the possibility that cores and/or flakes have been added or removed from the assemblage. Refitting provides a far more reliable basis for estimating the 'length of reduction' (ie. number of flakes) carried out on each cobble. Interpretations of the extent and sequence of reduction at the Page Creek quarries are therefore based on refitting flakes and cores. Five distinct knapping floors were identified on the two quarries on the Page Creek ridge, each represented by a spatially isolated concentration of artefacts. All artefacts in these knapping floors were collected and subjected to a refitting analysis. The result was the reconstruction of conjoined sequences that represent the flaking of nine different cobbles.

Refitted sequences could be described in detail. Even missing flakes, indicated by gaps in the refitted cobble, could be counted and have a number of characteristics measured, including an estimate of weight based on the volume of missing material. This enabled estimates of the original weight of the cobble, and of the amount of stone removed from the cores. Prior to the initiation of knapping these cobbles varied dramatically in size, from 1.5 kg to 8 kg. Extent of reduction also varied between cobbles. Measured as the weight of rock removed reduction varied from 734 grams to 7.5 kg. In terms of the number of flakes removed cobbles varied from 11 to 47. Much of the variability in the extent of reduction relates to the two major problems these knappers faced:

1. The establishment of a suitable platform, and
2. Maintenance of the core face in an appropriate state when the removal of large flakes from this greywacke had a high likelihood of generating step terminations that would leave a large mass at the base of the core.

Reduction of all nine refitted cobbles, and all other cores observed on the quarries, followed the same general strategy. Flakes were struck, by hard hammer direct percussion, down the long axis of the cobble, from a single platform. Production of a platform was usually accomplished by striking one or two large flakes. Very little choice was available for the position of initial blows because most of the cobble surface was covered with cortex more that 1cm thick. Cobble selected for reduction had one surface with relatively thin (1-3mm) cortex that appeared to be hard and smooth compared with cortex covering the rest of the cobble. Prehistoric knappers applied their first blows to those surfaces, typically removing large flakes across the short axis of the cobble to yield conchoidal surfaces that could serve as a platform. The number of flakes subsequently struck from the platform was clearly related to the flatness of the surface created by the initial large flakes. If the flakes setting up a platform terminated abruptly or produced radically undulating surfaces, the capacity to reduce the core was often greatly limited.

Cross-sections through reconstructed cobbles reveal the strategy of flake removal, and the problems of core shape that threatened to prevent further reduction (Figure 3). The undulation in the platform surface shown in Figure 3c created a barrier to extended reduction and the core was abandoned after only eleven flakes were removed. In contrast the gently curving platform surface depicted in Figure 3a imposed no major problem for reduction, and forty-six flakes were struck from the cobble.

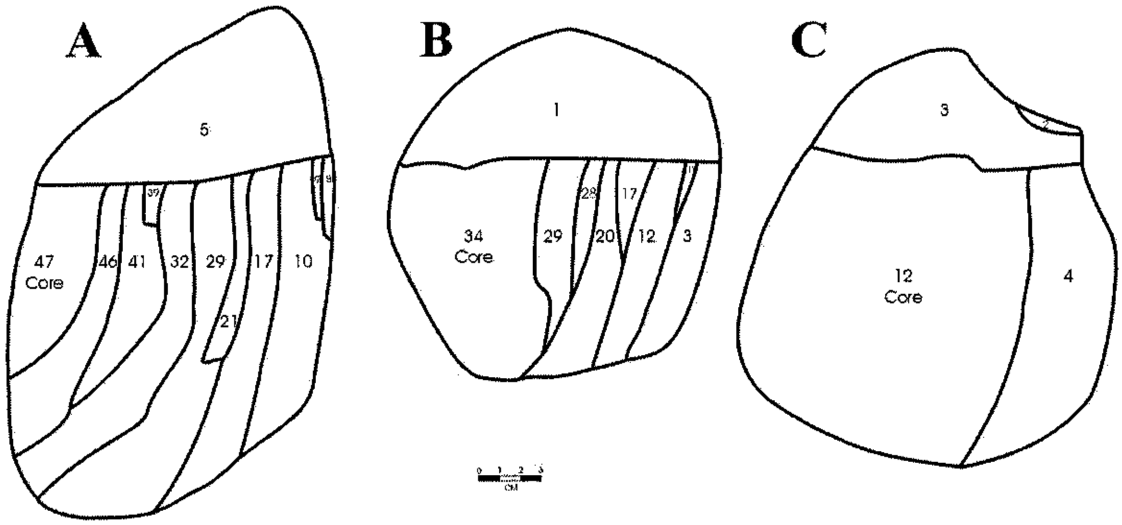

Figure 3. Cross-sections through three cobbles from Page Creek Quarry 1.

Once a platform was established the main threat to continued reduction was the production of abrupt terminations on the core face. To remove such terminations, and thereby prolong reduction, knappers employed five specific variations in the location of their blows. In order of the frequency of application these procedures were:

1. Striking the platform to the side of step terminated scars.
2. Striking further from the core edge.
3. Removing platform overhang.
4. Production of outrepasse terminations.
5. Initiation of a second platform positioned to remove the base of the core.

Since all five procedures are displayed in a single refitted sequence we can infer that they were probably known to and used by all knapper who worked at the quarry, but each procedure was employed only in suitable circumstances. This inference leads to an obvious but intriguing conclusion, that the archaeological manifestation of a stoneworking technology reflects the circumstances confronting the knapper. In any stoneworking technology, the knappers possess a repertoire of strategies and techniques they can employ to rectify emerging difficulties with the artefact being worked. Any problem can be prevented or solved by the application of only a limited portion of this repertoire, and so the emergence of a given problem in the reduction of one nodule is likely to elicit from the knapper behaviour that might not otherwise occur. Moreover, in some technologies a knapper may have more than one viable response to particular problems. Choosing one response rather than another may affect the size and shape of the resulting core and create circumstances in which different problems emerge which in turn will require their own particular solutions. The result can be reduction sequences that diverge as the cumulative effects of these choices alter core morphology. The implication for an understanding of stone working is that a variety of technological procedures may be applied by knappers within one 'technology' and it is possible for there to be a number of different archaeological manifestations of that technology. The success or failure of these problem-solving procedures, and the way that their application causes sequences diverge, can be measured in two ways, each dependent on conjoining.

MEASURING THE ONSET OF PROBLEMS

Creation of abrupt terminations on the core face potentially reduces the capacity to continue reduction. A description of the timing and magnitude of these alterations to the core face has the capacity to assist our understanding of the knappers struggle to control core shape. Refitting provides the opportunity to measure the changing rate and severity of abrupt terminations through the sequence of reduction. Figure 4 illustrates for one cobble the abundance of abrupt terminations at different points in the reduction process. Two patterns are apparent. Firstly, after the platform was created and cortex stripped from the core face, thereby creating a pattern of scars, a series of blows regularly produced feather terminations (see Figure 4a). These flakes were comparatively thick, with expanding lateral margins, but had feather terminations because they ran the entire length of the core. As the mass of the core decreased, and thin flakes were often removed from a flat core face, there was a gradual but consistent, seemingly inexorable, increase in the proportion of flakes with abrupt terminations. The directionality of this trend, sustained over a sequence of thirty flake removals, suggests that the knapper would have been aware of the gradual emergence of unsuitable features on the core face, but was unable to prevent the continuing production of these terminations. The continued reduction suggests that either feather terminations were not an essential requirement of flakes being produced (see below) and/or the knappers were prepared to continue investing energy despite the ongoing difficulties. A second pattern existed within this trend of increasing abrupt terminations (see Figure 4b). During the final stages of core reduction step terminations were very frequently produced. The onset of this high frequency production of step terminations was extremely sudden, and marked the transition of core size and morphology to a state in which production of feather terminated flakes was extremely difficult. One consequence of this trend was that the frequent step terminations at the end of the reduction sequence produced cores with protruding mass near the bottom of the core. This was a common pattern emerging in the reduction of cores continued at Page Creek.

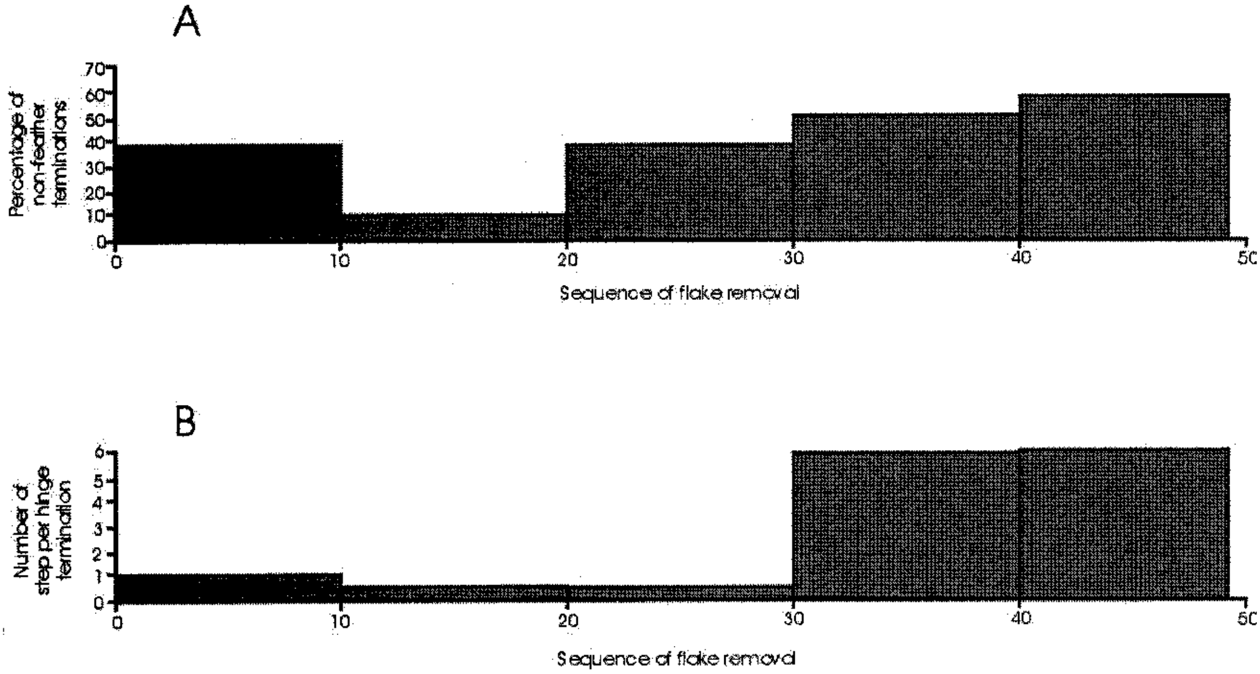

Figure 4. Histograms revealing the variation in flake termination frequencies during the reduction of one cobble, measured by a) the frequency of non-feather terminations, and b) the ratio of step:hinge terminations.

TRACING THE REDUCTION PROCESS

The knapper's success in maintaining the core face free from abrupt terminations can be evaluated by measuring the stability of core shape through the reduction process. A simple index of core shape, constructed as area of the platform surface divided by cross-sectional area of the base of the core, was used to evaluate the degree to which abrupt terminations have caused the core base to protrude. Values less than one represent a protruding core base, while values much greater than one indicate a contracting core shape with acute platform angles. Smaller values imply increasingly greater problems for continuation of flaking from the existing platform.

Examination of the core shape index for thirty cores recorded at Page Creek Quarry 1 reveals a distinct relationship between the weight of cores when discarded and their shape (see Figure 5). This relationship can be expressed in a number of ways. One way is to note the inverse pattern of observations. For core shapes values higher than 1, core weights are one kilogram or less; whereas for core shapes less than 1 many cores were discarded when they were still substantially heavier than one kilogram. A Lowess curve fitted to 80% of observations illustrates the tendency to higher weights at discard with lower core shape indices (see Figure 5).

Another way to understand size/shape relationships on these cores is to examine the thresholds that appear to mark points at which specimens are likely to be abandoned. Two thresholds are suggested. One is simply core weight: if cores have been reduced to 450-600 grams they are discarded at that size irrespective of core shape. This value is called the 'core weight threshold' (see Figure 5). The other factor obviously linked to core abandonment is the extent to which the base of the base of the core protrudes beyond the platform. Designated the 'core shape threshold' in Figure 5, this value (approximately described by the equation *core weight* = *-14.4* + *26.19* * *shape index*) characterises the relationship between core size and shape which represents the limits of reduction for the prehistoric knappers at Page Creek. Together these two inferred thresholds probably mark the boundaries of viable reduction using the techniques and strategies described above. Note the way that many of the recorded cores lay along the inferred thresholds, indicating that these are zones of morphology and size in which discard is much more likely.

Figure 5, plotting thirty abandoned cores, reveals the pattern of discard but does little to explore the process by which cores reach those final states. Questions concerning the uniformity of core reduction at and immediately prior to the moment of discard can be answered by examining these data, but to comprehend the variation of reduction throughout the knapping process further information is necessary. This additional information can be found in the nine refitted cobbles, where conjoining allows core shape and weight to be calculated for not only the start and end of the manufacturing process, but also *for all points during* each reduction sequence. By measuring the reconstructed cores at different stages in their manufacturing history it is possible to examine the changing relationships between mass and shape as reduction continues. Figure 6 plots the changes in the weight and shape index of these nine cores throughout their reduction. By charting the entire history of core reduction in this way several patterns are revealed.

The general trend that can be observed is that as reduction proceeded the shape of the core increasingly altered towards relatively smaller platforms, and large bases. This trend reveals that on most cobbles the knapper was unable to maintain core shape. Where core shape attained values less than 0.9-1, the specimen was typically abandoned at the core shape threshold when it was still well above the minimum size to which cores with other shapes could be reduced.

However while following a single strategy the reduction of these cobbles was varied. For example, the direction of change in core shape differs between cobbles, most showing a decline in the shape index during the manufacturing sequence, but some display a slight increase in the index with reduction. Even within the reduction history of a single cobble there are changes in the direction of change in core morphology. Two of the refitted cobbles show a dramatic reversal in core shape late in the sequence of flake removal. Other cobbles show minimal alterations in core shape despite the reduction of substantial amounts of material. These differences represent the contrast between reduction sequences that reveal dynamic instability in core morphology and sequences that reveal the knapper removed flakes while keeping the core morphology in a stable state.

One pattern that is apparent is that prior to discard of the core its morphology and size often changes parallel to one of the discard thresholds during the removal of a number of flakes. This reflects the emergence of abundant problematic features, such as multiple step terminations, late in the reduction sequence, and suggests that during the terminal stage of flaking many cores knappers often struggle to maintain or correct core morphology before eventually abandoning the object.

More significantly, the variation between cobbles in the direction of alteration to core morphology during reduction reveals that at Page Creek there was no necessary relationship between the initial and terminal core morphology. Cores were discarded at similar sizes and shapes even though they began the reduction process in radically different states; and conversely cobbles of similar sizes and shapes produced distinctly different cores. The inability to predict outcomes in any simple way is an outcome of the contingency of the complex process of knapping. Particular events in flake removal, such as the production of an undulating platform at the beginning of core reduction, or an outrepasse or step termination in the final stages of reduction, may alter the direction and ultimately the outcome of the flaking, perhaps eliciting knapping actions that would not otherwise have been employed. The existence of these situationally determined (or evoked) shifts in knapping behaviour and artefact morphology may confound inferences about all phases of the manufacturing process based on a simple analysis of end products. This conclusion emphasises the importance of studying process rather than static discard products; and, since this example illustrates the capacity of refitting to reveal sequential changes in the reduction process, it can be argued that conjoin analyses deserve a central role in describing stoneworking technology.

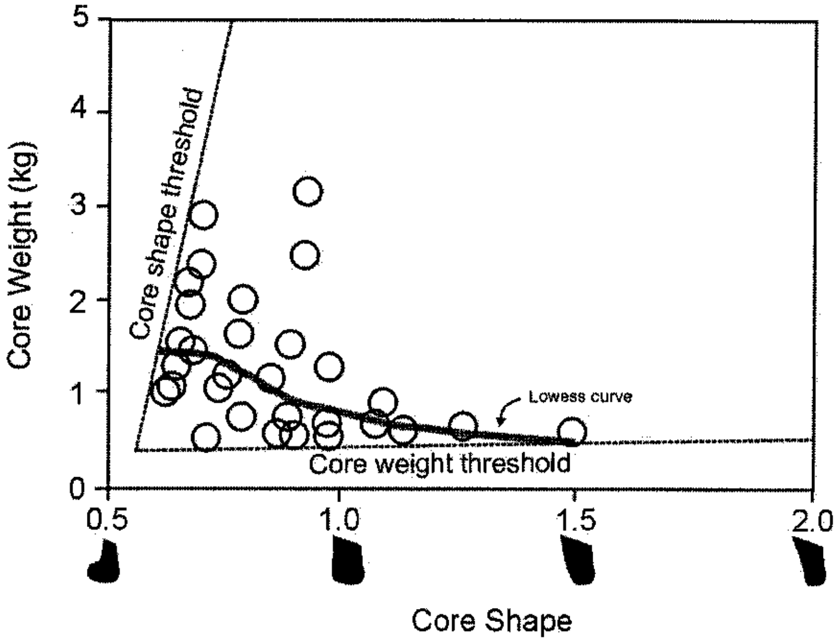

Figure 5. A scatterplot of weights and shapes for cores recorded at Page Creek, showing inferred discard thresholds.

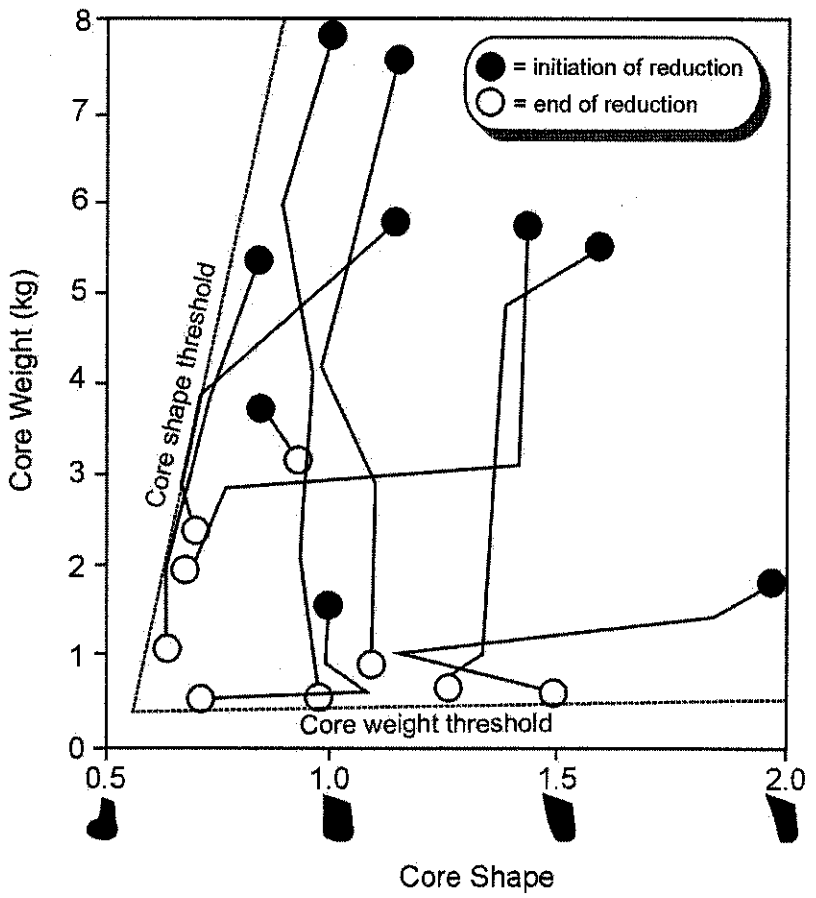

Figure 6. A scatterplot of weights and shapes for refitted cobbles, showing weight and shape of each core at different points during its reduction. Solid circles represent the core at the start of reduction, hollow circles represent the discarded core, and connecting lines trace the changes in shape and size during reduction.

MISSING FLAKES AND POINT PRODUCTION

Refitting is the only technique that provides detailed information about artefacts manufactured at a knapping floor but not recovered. At the Page Creek knapping floors many flakes were missing. Conjoining revealed 45.9% of flakes that had been struck had been removed from the location of production. It was relatively large and elongate flakes, with no cortex, low angled symmetrical cross-sections and feather terminations that were selected and carried away from the quarries. Flakes of this kind produced more frequently later in the sequence, and it follows that missing flakes are typically much more frequent in the middle to late stages of reduction. Figure 7 illustrates changing frequencies of removed flakes in a single refitted sequence, revealing a typical pattern of greatly increased rates of flake selection late in the sequence when curvature and ridges on the core surface facilitated production of elongate flakes.

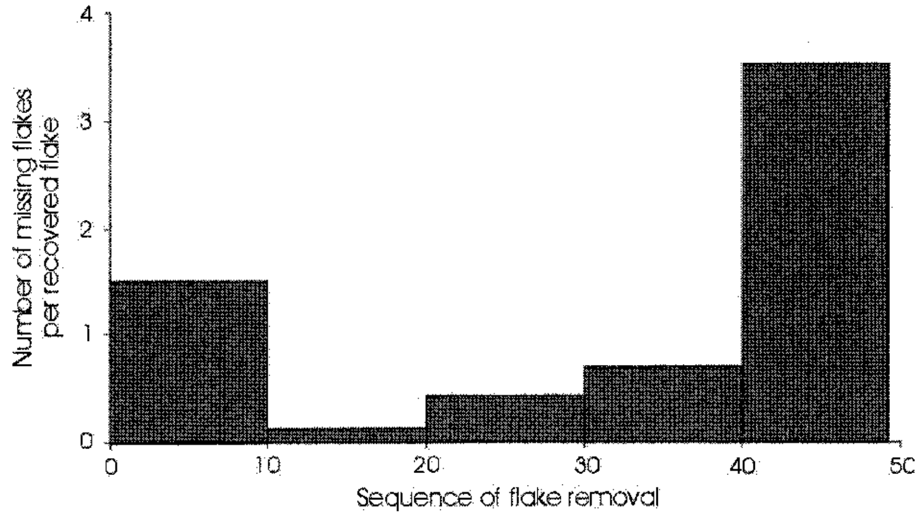

Figure 7. Histogram showing changing frequencies of missing flakes in one refitted sequence from Page Creek.

Measurements of these missing flakes were taken from the cavities created by refitting the surrounding flakes. These measurements indicate that only flakes of a very specific size and shape were being removed for use and/or retouching elsewhere. In particular the selected (ie. missing) flakes displayed a strong linear relationship (r^2 of 0.9224) between length and elongation. The regularity of flakes selected for transportation elsewhere suggests a coherent set of characteristics were required, and that all missing flakes were selected for the same scheme. A comparison of these missing quarry flakes with unifacial and bifacial points made on greywacke and found in the same region indicates that the missing flakes were suitable for manufacture into retouched points. This is shown in Figure 8 by a plot of the missing flakes and of 27 complete greywacke points found within a 10km radius of the quarry. Points also display a positive relationship between size and elongation, but are off-set from the data points of missing flakes because retouching of the lateral margins has increased the elongation for a specimen of a given length. It is likely that the retouched points were manufactured on blanks that were similar to the flakes removed from the Page Creek quarries. Consequently the missing flakes are hypothesised to have been removed for conversion into unifacial and bifacial points.

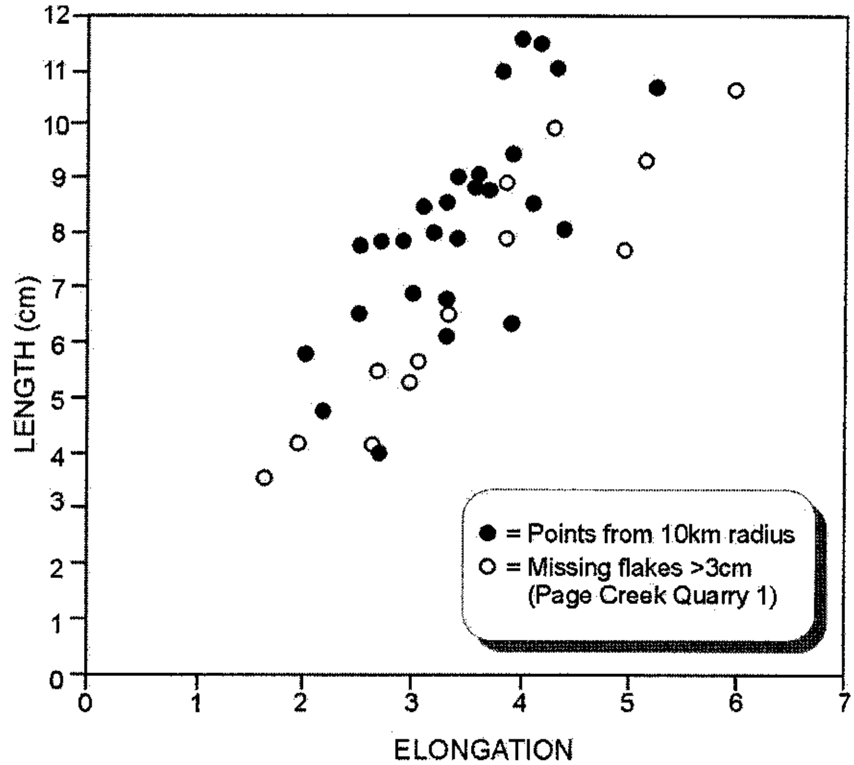

Figure 8. Scattergram comparing dimensions of missing flakes and bifacial points in the vicinity of Page Creek.

This inference is reinforced by information about the nature of point reduction. Hiscock (1994) has demonstrated that in the Lawn Hill region, as in other areas of northern Australia, there is a technological continuum from unifacial to bifacial points, as the former are gradually transformed into the latter by re-sharpening and re-shaping. This reduction of flakes to form points was an activity not carried out on the quarries. Retouching of the points continued as they were transported around the landscape, broken, re-shaped and re-hafted. When flakes were removed from the greywacke quarries they were usually retouched by removing flakes from along one lateral margin on the dorsal surface. At a later time the second margin might have been flaked in a similar fashion. And eventually one or both of these margins might have been made bifacial by the removal of flakes from the ventral surface. This gradual process of reduction displays a spatial variation, as points are transported and increased reduction increased the proportion of points with bifacial retouch. Figure 9 shows the rise in the abundance of bifacial points with increasing distance from the Page Creek quarries; a pattern that could be expected if flakes produced at those quarries were removed for conversion into retouched points.

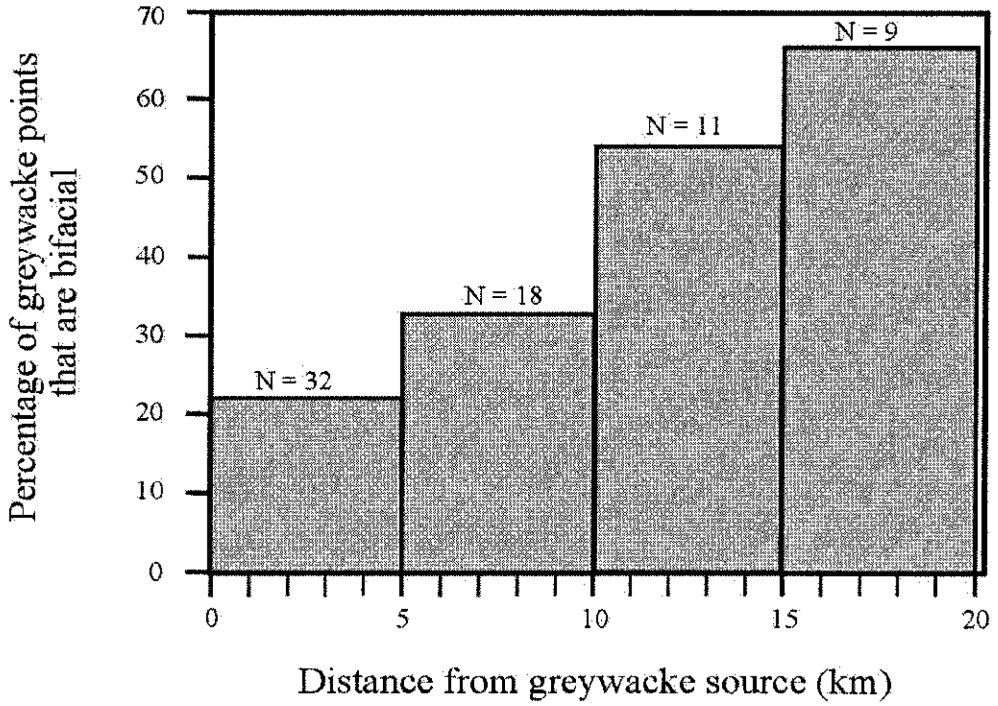

Figure 9. Histogram showing the increase in bifacial points with distance from the Page Creek quarries.

CORE TRANSPORTATION AND REDUCTION

Flakes that could be made into points were not the only artefacts removed from the greywacke quarries. Small cores were also carried away for reduction at other localities. Refitted sequences have been obtained from two sites within a short distance of the Page Creek sources. Mount Jennifer 1 is 2.2 km from Page Creek and consisted of thirty greywacke artefacts scattered over a 5 m^2 area. This debris was subjected to a refitting analysis, with eighteen of the specimens being conjoined. In conjunction with observations of raw material variation the refits demonstrated that the assemblage derived from four different cores although only one was discarded at Mount Jennifer 1. The longest conjoin set consisted of seven flakes revealing a sequence of ten flakes removed from a core. The second site was Mount Jennifer 2, a scatter of eleven greywacke flakes spread over a 4 m^2 area, located 4.5 km from Page Creek. These flakes derive from three cores, although none were discarded. Six of the flakes were refitted into one conjoin set, revealing three missing flakes in a sequence of nine flake removals. Taken together the refitted artefacts from the seven cores represented by flakes at these two sites reveal details about core reduction on the plains away from the greywacke source.

Knapping strategies applied to these cores were different from those employed on the quarries on Page Creek. Away from the quarry knappers rotated the cores, preparing a number of different platforms and changing platforms regularly as a device to help maintain core shape. The result was that shape indices for cores found away from the quarries ranged between 1 and 3, indicating that these cores typically had platforms larger than core bases. Figure 10 uses a single refit sequence, from Mount Jennifer 1, to illustrate the cyclical patterns in the knapper's actions and in the resulting flakes that is associated with this strategy of core rotation. Flakes struck off a new platform were relatively large but decreased in size as reduction from that platform continues (see Figure 10a). Trends towards smaller, squatter and more irregular flakes during flake removal from each platform resulted from the increase in hinge terminations and flatter core faces. Abrupt truncation of the fracture caused shorter flakes and flatter cross-sections resulted in the fracture plane spreading out and causing squat flakes rather than being directed along the percussion axis to cause elongate flakes. These trends are eventually terminated when the knapper relocated blows to an alternative platform. The sequence of blows to the new platform typically displayed similar trends. The number of flakes struck from each platform, and hence the periodicity of these cycles, was variable. In the refitted sequence illustrated in Figure 10 the number of flakes struck from a platform prior to rotation ranges between one and four.

This variation in the number of flakes removed from each platform reflects, at least in part, from the success of core rotation as a means of maintaining appropriate core morphology. The refitted sequences, including that reported in Figure 10, reveal the condition of the core immediately prior to the switch to a new platform, and these core conditions can be used to infer the factors that trigger core rotation. Cores were rotated to a new platform when the flakes being removed dropped below 3.8 cm in length, or 1.1-1.3 in elongation index, or the platform angle dropped below 80°. These characteristics stimulated core rotation, even if only one flake had been struck from a platform. The cyclical patterns of flake size morphology induced by regular core rotation reflect the recurrent emergence of problems and the application of temporary solutions. The problems that recurred were related to the development of inappropriate core shapes in a condition of low inertia. Because the inertia of the core was low relative to the size of flakes being removed from it, the likelihood of desirable flakes being removed was easily altered by subtle changes in core shape or size. The continual removal of relatively large flakes with prominent bulbs almost inevitably resulted in the presence of pronounced overhang and decreased platform angles. This led to short flakes and flakes with hinge terminations, which left prominences on the lower part of the core face. Without pronounced ridges to strike down, the prominences left by short and truncated flakes were impossible to remove by continued use of the same platform. This was the problem encountered by the knapper, and without a solution it would most likely have necessitated abandoning the core. It is not possible to determine what characteristics allowed the knapper to perceive the approaching threshold but the trends, such as the dramatic decrease in flake size, must have been apparent. Core rotation was the solution employed by the knapper. By changing platforms it was possible not only to continue reduction, but also to remove the problematic features on the old face of the core and alter the characteristics of the old platform. The advantage of this procedure was that when a problem recurred other platforms and associated core faces were often available to allow reduction to continue. Eventually, of course, this strategy of reduction would meet difficulties for which the knapper had no solution

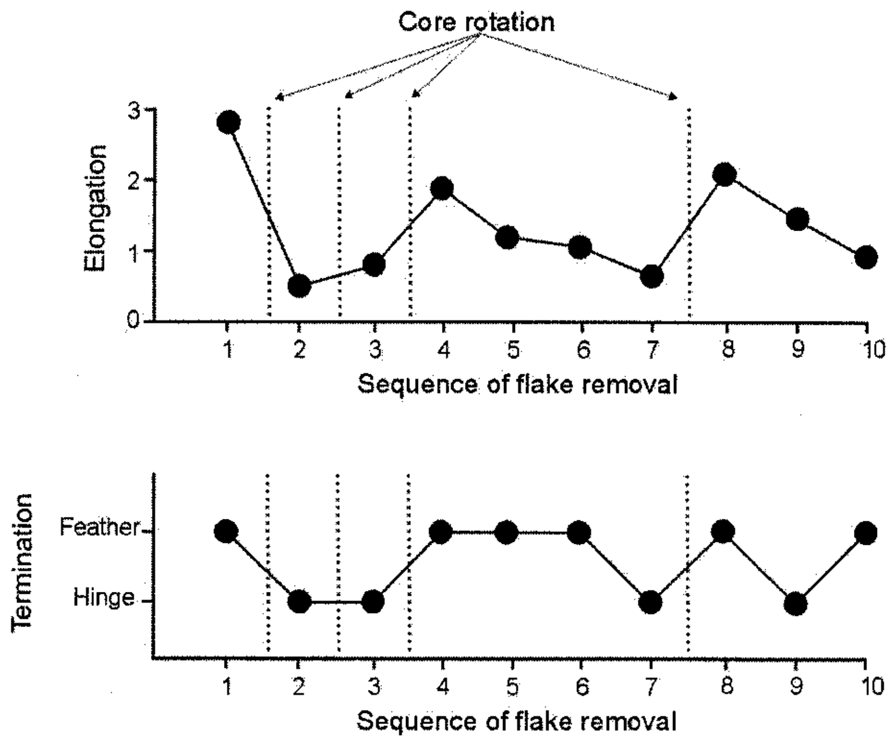

Figure 10. Sequential changes in flakes removed from a refitted sequence away from Page Creek.

The degree to which this procedure facilitated reduction is shown by the average weight of 38 grams for cores discarded away from the quarry, less than one-tenth the weight of the smallest core produced by knappers at the quarry. Using this observation and adding information obtained from refitting it is possible to calculate the amount and structure of core reduction that took place away from the Page Creek quarries. This calculation can be developed as follows:

- At the Page Creek quarries the weight of cores when they were first carried away is based observations of cores weighing less than 1,000 grams that had appropriate morphologies for further reduction, namely not having developed low platform indices but being too small to produce the long flakes suitable for point manufacture. Such cores ranged between 474 and 954 grams, with an average of 632 grams. This average figure is employed as an estimate of the typical cores carried off the quarries.
- Since the average weight of cores discarded away from the quarry is only 38 grams, I calculate an average of 594 grams of material was removed from cores being transported around the landscape.

- The average weight of flakes away from quarry, at sites like Mount Jennifer 1 and 2, is 13 grams. Simple calculations indicate that 46 flakes of this weight could have been produced from the 594 grams removed from cores in off-quarry contexts.
- Refitting of artefacts at Mount Jennifer 1 and 2 indicates that on average 6.6 flakes were removed from each core at a single location (with a range of 2 to 10 flakes per core per locality). This figure can be used to suggest that the 46 flakes struck from the average core were removed in knapping on about on 5-8 occasions, with an average seven different occasions.
- Finally, the refitting at sites way from the quarry indicates that each time the knapper worked the core, about two or three flakes were not discarded on the spot but were carried away, presumably for use. This implies that about 30% of flakes made at these off-quarry knapping floors were removed for use elsewhere.

Even acknowledging that such a calculation is built on numerous average values, and therefore fails to express the variation that must have occurred in prehistoric behaviour patterns, it provides a useful heuristic for describing the general scale and structure of core reduction. In particular, this kind of rough calculation supports the suggestion that cores were carried around the landscape as a convenient source of flakes.

CONCLUSION

Refitting of knapping floors in one region of northern Australia has been used to help analyse the production technology employed during the mid-late Holocene. The focus of this example is on the production of flaked artefacts at a number of quarries on one raw material source, and the distribution and further reduction of artefacts in the local landscape. At outcrops of the rock, knappers repeatedly used particular reduction strategy to produce artefacts that they carried to other parts of the landscape. The application of this approach was flexible in the sense that circumstances elicited different elements of the strategy. Large, elongate flakes of a particular shape were carried away and at least some were retouched to form unifacial and bifacial points. Cores were also carried away from the quarry, and flakes were struck off whenever they were required. Striking flakes from these small cores was accomplished by employing a strategy different to that at the quarry. Large single platform cores are dominant at the quarry, but away from the quarry the small cores were constantly rotated as they were worked. Rotating cores in this way removed undesirable features from the core and facilitated continued reduction, thereby rationing the material. The success of this strategy is indicated by the apparent ability of the knappers to employ small greywacke cores as a portable source of flakes as they moved about the landscape. These strands of information combine to provide a picture of the technology employed by prehistoric humans knapping greywacke in this locality, and at the same time illustrate the value of refitting for these kinds of technological analyses.

These inferences highlight benefits that have long been acknowledged in refitting studies. Refitting provides a capacity to reconstruct and measure the sizes and shapes not only the discarded core but also of those cores at earlier stages in their reduction history and even the initial cobble. This potential is particularly pronounced in lengthy reduction sequences, in which early stages of reduction have been removed by later ones. One reason that this ability to measure artefact form at all stages is important is that extended reduction may, at least in some cases, standardise the size or shape of the object being worked, thereby hiding variability that may have existed early in the reduction process. Complete reconstruction of knapped blocks through refitting is the means by which such possibilities can be tested.

This also reflects one of the ways refitting can assist the study of technological variability rather than simply the construction of normative depictions of stoneworking. The ability that refitting adds, to study all stages of reduction by providing a sequential order for the activities evidenced, encourages more elaborate depictions of the reduction process. Examples of these opportunities have been provided in this paper. The notion that initial reduction of cores can enlighten us about the repertoire and preferential selection of actions in a technological system, as knapping problem elicit responses from the knapper, signals an approach which is sensitive to differences in stoneworking at different scales (differences in the work of one knapper in different situations, differences between knappers, and differences between groups of knappers, and so on). The variability that can be revealed by studying the contrasts between refitted sequences in often hidden in other analytical approaches. For instance, depictions of reduction processes obtained by seriation of different artefacts typically begin with the presumption that only a single system of reduction exists and that variation within that system is minimal. Refitting not only avoids the need to assume minimal variation but also encourages non-normative explorations of the archaeological record by facilitating an examination on human activities involved in the production of all components of the preserved assemblage, without presupposing that information resides only in 'end-products'. In this way refitting studies greatly contribute to descriptions of the overall production system.

The pursuit of information about variation obtained through this examination of the ancient Australian technology reveals issues of general interest. For example, the variation between cobbles in the direction of alteration to core morphology during reduction reveals that at Page Creek there was no necessary relationship between the initial and terminal core morphology. Cores were discarded at similar sizes and shapes even though they began the reduction process in radically different states; and conversely cobbles of similar sizes and shapes produced distinctly different cores. This conclusion echoes the recent findings of De Bie and Caspar (2000:116) who argued that in many instances the characteristics of abandoned cores did not necessarily reveal manufacturing processes that had been applied to them at early stages in their reduction. They too conclude that only refitting provides a means of describing the entire reduction process.

That verdict is also demanded, as many archaeologists have noted, when refitting identifies characteristics of absent forms. No other observation can document those artefacts removed from an assemblage. In the case study presented here the shape and size of missing flakes, the timing of their production, and the similarity of their form with bifacial points were established only by reference to the refitting analysis. In the same way, the information obtained from refitting in this study facilitated inferences about the length of reduction sequences (that is the number of flakes struck), the variation between refitted sequences, and the causes for that variation. Refitting analyses provide this information with a precision and detail that is absent from non-refitting approaches such as the calculation of flake:core ratios.

None of the inferences outlined here, or the conclusion to which they point, are likely to be as accurately inferred without refitting. For this reason refitting forms a key methodology that can be employed in analyses of prehistoric stoneworking. What this paper advocates is the desirability of developing approaches that integrate refitting with other analytical techniques (such as attribute analyses), and which facilitate the quantitative depiction of trends that are revealed by refitting. By employing refitting studies within a composite analytical framework the power of refitting can be exploited in studies of variability in past production systems and their articulation within regional systems of manufacturing and artefact use. The quantitative examinations of regional patterns in Holocene reduction technology in Australia presented here hint at the opportunities that exist for extracting information from refitted lithic artefacts.

School of Archaeology and Anthropology,
Australian National University,
Canberra, A.C.T., 0200,
Australia

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Figure captions

Figure 1 Examples of bifacial points from northern Australia showing progressive reduction from unifacial and unimarginal retouch (left) to bifacial and bimarginal (right).

Figure 2. Map showing the location of the Page Creek quarries in northern Australia.

Figure 3. Cross-sections through three cobbles from Page Creek Quarry 1.

Figure 4. Histograms revealing the variation in flake termination frequencies during the reduction of one cobble, measured by a) the frequency of non-feather terminations, and b) the ratio of step:hinge terminations.

Figure 5. A scatterplot of weights and shapes for cores recorded at Page Creek, showing inferred discard thresholds.

Figure 6. A scatterplot of weights and shapes for refitted cobbles, showing weight and shape of each core at different points during its reduction. Solid circles represent the core at the start of reduction, hollow circles represent the discarded core, and connecting lines trace the changes in shape and size during reduction.

Figure 7. Histogram showing changing frequencies of missing flakes in one refitted sequence from Page Creek.

Figure 8. Scattergram comparing dimensions of missing flakes and bifacial points in the vicinity of Page Creek.

Figure 9. Histogram showing the increase in bifacial points with distance from the Page Creek quarries.

Figure 10. Sequential changes in flakes removed from a refitted sequence away from Page Creek.