Reduction Continuums and Tool Use

Peter Hiscock and Val Attenbrow

Abstract
This paper focuses on a contradiction between two central principles frequently embedded in lithic studies: the notion that implement form often reflects intended function because prehistoric artisans designed specimens to be functionally specific and proficient, and the notion that there is often a progressive alteration of implement form during its use-life. Tension between these two seemingly incompatible propositions creates an interpretative paradox that we have expressed with the question: “how can implements be designed for, and be efficient in, a specific use if their morphology is continuously changing?” We illustrate the interpretive difficulties arising from this question through an analysis of a classic Australian site, Capertee 3, at which we document a pattern of change in edge characteristics of retouched flakes (often called ‘scrapers’) during the reduction of each specimen. Drawing on this case study we explore the implications of this contradiction for interpretations of Palaeolithic assemblages. Our conclusion is that further studies and theorising are required to help archaeologists move beyond the naive presumption that conventionally recognized implement types have a simple association with particular uses and that by implication those types must be designed to be efficient in the particular use to which it was constructed.

Introduction
One of the persistent myths of Palaeolithic research is that stone implements are always, or at least dominantly, designed to efficiently carry out a specific function. This notion has pervaded analyses of stone artefacts on all continents since the beginnings of modern archaeology, and is embedded in the interpretation and even the names applied to many implement types. Examples of this view can be plucked from published works decades apart, revealing the robust and ingrained nature of this functional perspective on stone implement variability. From Binford’s (1973) famous conclusion that for the European Middle Palaeolithic “A reasonable suggestion as to what Bordes’ taxonomy is measuring is the character of differentiation in the design of tools as such” to Bisson’s (2001:167) recent statement that “The primary constraint on tool form is, of course, function”, the view that stone implements are designed to be functionally efficient is explicit.

Elements of these functional propositions have been challenged by arguments that implements do not have stable morphologies but actually display progressively changing sizes and shapes until they were discarded. In particular there is a plethora of studies showing that in many sites unifacially retouched flakes form a pattern of continuous morphological variation, reflecting the continuous reduction to which some specimens are subjected. This paper investigates some of the implications of these reduction continuums for our understanding of the use of these implements as tools. In particular we pose the obvious but little discussed question: “how can implements be designed for, and be efficient in, a specific use if their morphology is continuously changing?” An Australian case study is employed to explore the magnitude of the problem contained within this question, to evaluate alternative explanations for variation in implement morphology, and illustrate potential methods by which these issues can be examined. However, the appropriate starting place for this exploration is the foundation principles that have long been recognized by researchers arguing that form follows function in the production of variability in assemblages of stone artefacts. Explicit statements of these principles can be exemplified, not with Australian publications, but by using two celebrated papers from North American researchers.

The idea that tool form reflects functional constraints or intentions is often manifested in arguments about the characteristics of the retouched edge. Most notably researchers often associate the plan shape/position and cross-sectional angle of retouched edges with the nature of intended use. Such an argument was contained in two seminal papers published in a single volume of American Antiquity 35 years ago (Frison 1968; Wilmsh 1968). In the first of these papers Frison (1968:152) framed the key theoretical statement that “working edges must be right for the task at hand”. This proposition, held by many archaeologists then and since, was explored by the second of these papers in which Wilmsh (1968:156) hypothesized that frequency modes of implement edge angles within assemblages reveal broad categories of functional operations, claiming that “…the different angle sizes are related to different function” (Wilmsh 1968:159). For example, Wilmsh suggested that very low retouched edges (<40°) were functionally efficient for cutting soft materials; while medium angled edges (45-60°) were efficient for skimming, scraping and cutting of hard materials; and even steeper retouched edges
 (>65°) were best employed for uses that required more robust edges such as woodworking and bone working. Existence of a covariation between the type of use activity and the edge characteristics that were prepared in anticipation of that activity was considered to be a primary explanation of the morphology of retouched flakes recovered by archaeologists. Discussing the posited form-function relationship Wilmsen (1968:160) concluded:

An attempt has been made to account for formal variation in stone-tool inventories. A functional foundation has been postulated for most of this variation. While the technical basis of tool modification is recognized, it is clear that modification was directed toward improving the functional qualities of tools and that, therefore, the specific character of this modification should provide insights into the actual functional role of any set of tools.

This principle has a long history in archaeological inference, and although the Wilmsen article in particular stimulated research projects that deduced the use of both individual implements and implement types on the basis of edge angle (e.g. Fergusson 1980), the presumption that intended function was the central cause of implement morphology has been independently employed by many researchers. Indeed, the quintessential historical debate in Palaeolithic variability focused on the sparring between Bordes (1961, 1972, 1973; Bordes and de Sonneville-Bordes 1970) and Binford (1973; Binford and Binford 1966) concerning the explanation for Mousterian assemblages, and involved assertions about the extent and manner in which implements could be interpreted in terms of their design for particular uses. Even when Dibble (1984, 1987) reshaped this debate by introducing the notion that the technology of manufacture was a significant factor in the construction of variation he advocated that this technology was principally involved in resharpening edges being used. Even in recent reviews we continue to receive statements about the primacy of design for use in creating implements, such as the statement that “…the morphology of Middle Palaeolithic scrapers is generated by functional contingencies, including intended use…” (Bisson 2001:180).

Underlying the presumption that implement types appear different because their makers shaped each in accordance with design rules relevant for their intended uses is the view that implement types are morphologically distinct from one another, with not only a strong tendency to similarity of specimens within each type but also clear morphological/size discontinuities between types. These principles typify typological approaches to stone artefacts, presupposing that perceived types reveal designed tools that are morphologically distinct (see Hiscock in press a; Whallon and Brown 1982). We label this viewpoint a ‘segmented’ model of implement variation, reflecting its advocacy of discontinuous implement morphology, as illustrated in Figure 1. In typological analyses of Palaeolithic assemblages it is commonly implied that each segment of the discontinuous morphological variation, supposedly recognized as a ‘type’, represents a functional category for which that morphology is efficient. Such a model represents one way that a technology could create archaeological implements.

An alternative structure for archaeological assemblages is a pattern of continuous rather than discontinuous morphological variation; a pattern we label the ‘continuum’ model of artefact variation. As illustrated in Figure 1 this structure is in theory distinguished from segmented patterns simply by the absence of any significant breaks in the morphological range visible in large assemblages. This continuum model has occasionally been invoked for Australian artefacts (see Hiscock and Attenbrow 2002, 2003), but has been more consistently emphasised by northern hemisphere researchers studying variation within assemblages of bifaces. Continuum models of this kind have often been used to argue that morphological variation primarily reflects differences in the extent to which specimens have

![Graphical representation of the difference between segmented and continuum models of morphological variation.](Image)
been reduced. The linking of continuum models with explanations invoking differential degrees of reduction has now been shown to be a powerful depiction of implement variation in the Old World (e.g. Dibble 1984, 1987, 1995; Gordon 1993; Hiscock 1996; Holdaway et al. 1996; Kuhn 1992, 1995; McPherron 2000; Neely and Barton 1994; Rolland and Dibble 1990).

The recognition that artefact morphology is modified during reduction has been explicit for more than a century (e.g. Holmes 1893), and those classic discussions of form and function cited above acknowledged this mechanism in their considerations. For instance, Wilmsen (1968:159) suggested that as resharpening proceeded the angle of retouched edges would increase. This posed a problem for the purported existence of a simple correspondence between angle and intended use, a predicament that Wilmsen (1968:160) recognised in the context of an illustration of form-function associations in hide-working tools:

> It may be, for example, that distal angles of approximately 50°-55° were useful for hide-working; that resharpening progressively steepened some of these angles to a point where they were no longer functional in their original task; and that these more steeply-bitted tools were then used for different purposes such as bone and wood shaping.

The perception of continuous modification of tool morphology in response to edge blunting was an issue that Frison (1968) focussed on in his highly cited paper. His central point was the proposition that discarded tools were probably dysfunctional. Frison (1968:149) framed this idea in the following way:

> Tools such as side scrapers, end scrapers, knives, and drills were continually modified throughout their lifetime of functional utility, and at the time when they were discarded or became non-functional, they were usually quite different than when originally completed.

By targeting the conditions leading to abandonment of a specimen Frison’s statement was not meant to deny a form-function association during much of the use-life of a tool, but is primarily concerned with the failure of discarded tools to retain morphological features that are indicative of their function. The implications of a morphological change immediately prior to, and perhaps provoking, discard of a tool is undoubtedly an important one for typological investigations into site function. However, that process is not as challenging for claims of form-function associations as Wilmsen’s suggestion that the use of a specimen may change sequentially in proportion to the extent of resharpening it has undergone.

Progressive change in the characteristics of retouched edges has been interpreted as a consequence of resharpening in many studies over the past two decades, a perspective to which Jelinek (1976) and Dibble (1984, 1987, 1995) attached the label the “Frison effect” in reference to Frison’s (1968) discussion of the process of reuse and remodification of tool forms. In fact the term “Frison effect” might be better restricted to the process of radical morphological change towards the end of the use-life of a specimen and immediately prior to discard or recycling; since that is the sense of Frison’s (1968) own discussion. A process of gradual morphological change throughout the entire existence of an implement, perhaps with minimal alteration in the rate or direction of morphological change prior to discard, is the pattern actually being referred to by Dibble (1984, 1987) and other recent researchers, and this is notionally different from what we recommend should be referred to as the “Frison effect”. For gradual morphological change throughout the existence of an implement we propose the term “Holmes effect”, named for the remarkable William Holmes (1890, 1891, 1892, 1893) who most powerfully asserted continuing reshaping of complex stone artefacts. It is this gradual change in implement morphology that has been the focus of many discussions of Palaeolithic variation in recent decades.

Although this mechanism has been widely discussed the implications for interpretations of use and use-form relationships have been little explored. For example, in the context of debates about Middle Palaeolithic implement variation a frequent assertion is that continuous change in implement morphology implies only a small number of functionally distinct categories, each displaying a range of morphological varieties created by different levels of reduction (e.g. Kuhn 1992:125). Another depiction of the changing implement morphology is that these were generalised tools, not standardised for a specific task (Kuhn and Stiner 1998). The questions: how many tasks were carried out by such tools and how a generalised tool would be employed have not been comprehensively examined. The imperative to explore these questions has grown as the diversity of Middle and Upper Palaeolithic typological forms recognised as representing phases of resharpening has grown to incorporate not only lateral and transversely retouched scrapers but also points, notches and denticulates (e.g. Dibble 1984, 1987, 1995; Gordon 1993; Hiscock 1996; Holdaway et al. 1996; Rolland and Dibble 1990). It is also common to note the absence of a simple form-function correspondence, such as the statement by Holdaway et al. (1996:377) that “…edge-wear analysis has demonstrated that there is no simple one-to-one correlation between tool form and function.” Dibble (1995:343) has concluded that the lack of association between morphological differences and functional differences is to be expected of, and is consistent with, reduction models of implement variation. However, in reaching that conclusion Dibble notes the importance of Beyries’ (1988) study suggesting use-wear differences between implement categories, but dismisses it because of the extremely small sample sizes involved in that study. Of course Dibble is correct to doubt the robustness of form-function discussions developed from small
We believe these various discussions reveal a number of aspects of the multifaceted association between Palaeolithic implements and the uses to which they may have been put. However, we also argue that in the archaeological literature the contradiction that exists between an expectation of a distinct form-function relationship and the demonstration of progressively altering implement form has been inadequately recognized and discussed. Consequently we advocate that assemblage analyses should regularly pursue the question we posed earlier: “how can implements be designed for, and be efficient in, a specific use if their morphology is continuously changing?” To begin the investigation of this question we present a study of the nature of morphological change on an assemblage of unifacially flaked stone implements from Australia. These ‘scrapers’ and ‘scraper-like’ artefacts have been chosen as a case study because of their similarity with one class of implements that have often been the subject of debates about both reduction continua and function.

The Example of Capertee
This example is concerned with the large collection of implements from Capertee 3, a rockshelter in the Blue Mountains west of Sydney. Artefacts from this site were employed by pioneer archaeologist Fred McCarthy (1964) in his description of the prehistoric sequence in eastern Australia. His typological analysis of the assemblages from Capertee 3 examined the dorsally retouched flakes, which he treated as discrete types, describing them variously as ‘scrapers’, ‘knives’, burins, and ‘saws’. McCarthy additionally noted the presence of notches and ‘noses’ on working edges. These categories and features were clearly regarded by McCarthy as having functional significance. This is indicated by McCarthy’s repeated use of the term “working edge” in describing the retouched portions of flake margins, and it is obvious that he thought the shape of the retouched margin was indicative of the nature of the use to which the specimen had been put. In some instances the inferred function was explicitly identified, such as when McCarthy (1964:238) concluded that “Simple knives...probably served as flesh cutters”; but in most instances the presumed function was merely implied by the name of the implement. The purported correspondence between typological groupings and function which McCarthy presented was influential in Australian archaeology and has survived until today in the work of conservative typologists (see Hiscock and Attenbrow 2003). For example, in their review of Pleistocene Australian implements Mulvaney and Kamminga (1999:217-219, 227) recognized categories such as ‘end scraper’, ‘straight-edged scrapers’, ‘notched scrapers’ ‘concave scrapers’, and ‘nosed scrapers’, attributing a different function to each.

The original typological description of the Capertee 3 assemblage, with its functional implication, involved the categorisation of different implement types on the presumption that a segmented model was an appropriate depiction of assemblage patterning. Our concern in this paper is to summarise the evidence for continuous scraper reduction in this assemblage, as detailed by Hiscock and Attenbrow (2002, 2003), and to then explore the implications of the assemblage pattern for functional statements.

A first question we ask is whether McCarthy’s depiction of separate, morphologically discrete types is an accurate representation of the assemblage. The alternative hypothesis is that differences between the various scraper-like implement types are arbitrary divisions of morphological continua and may be explained in terms of the extent of knapping each specimen has undergone (see Hiscock and Attenbrow 2002, 2003). This model predicts a positive relationship between morphological changes and the amount of retouching that has been applied to a flake, irrespective of whether that retouching was maintaining edges and/or generating flakes. Specimens that have received little retouch will have relatively straight retouched edges, with small retouch scars restricted to a short portion of the flake margin. In contrast specimens that have been extensively retouched will have longer more curving retouched edges, with larger retouch scars spread along much of the flake margins. This reduction model can be tested by making a number of observations about each specimen.

We use a number of quantitative measures to evaluate the relationship between retouch characteristics and extent of reduction on the scraper-like implements from Capertee 3. Our analysis does not incorporate flakes that have been backed, but deals with all of the measurable, complete, dorsally-retouched chert specimens in this scraper-like category in the Capertee assemblages. To this end we have excluded specimens that are technically cores, unretouched flakes or unmeasurable heat shattered fragments, and specimens made on materials other than chert; yielding a sample of 168 complete non-backed dorsally retouched flakes on which our measurements could be made. This sample includes specimens from all levels in Capertee 3 and is larger than the one used in our previous publications (see Hiscock and Attenbrow 2002, 2003). Although more than one third of the objects do not retain any information of McCarthy’s original classification, we know how he classed the majority of
these specimens (see Table 1). McCarthy had classified most of these specimens as scrapers or saws, with the remainder being called knives, burins, elouera and even cores.

Dorsal retouch on these specimens is both marginal and steep. For this reason we consider that Kuhn’s (1990) index of reduction is an appropriate measure of the extent of retouching. This index expresses retouch height (designated ‘t’) as a fraction of the possible height that could be obtained on that specimen (designated ‘T’). We applied Kuhn’s measurement at three places, evenly spaced, along the longest retouched edge of each specimen (see Figure 2), and calculated the average as \( \frac{t_1 + t_2 + t_3}{3} \), a value we refer to as the ‘Average Kuhn reduction index’. In this procedure our calculation is identical with that made by Hiscock and Clarkson (this volume). For the sample from Capertee 3 defined above this index varied between 0.12 and 1.00 (\( \bar{X} = 0.49 \), s.d=0.23). Since Kuhn’s index has the benefit of ranging between 0 and 1, it is clear that the specimens at Capertee 3 include those that had been minimally reduced as well as those that were far more highly reduced. Furthermore, as Hiscock and Attenbrow (2002, 2003) have demonstrated, the Capertee 3 assemblage displays a continuous, unimodal distribution of Kuhn reduction index values, consistent with a single form reduced by varying amounts, and without multiple modes that could hint of several overlapping but discrete classes.

We take values of this index to be positively related to the amount or extent of retouching for reasons explained by Kuhn (1990) and by Hiscock and Clarkson (this volume). Furthermore, in the Capertee 3 assemblage there is a strong positive association between the Average Kuhn reduction index and other characteristics of retouching that could also be expected to increase as reduction proceeds. For instance, there is a strong linear correlation between the Average Kuhn reduction index and the length of retouch on each complete specimen (\( r = 0.83 \), d.f.=154, p<0.001). In this regression analysis no constant is employed, thereby forcing the regression line through origin. Because the two variables compared must both start at 0 for a flake without retouch this is the appropriate regression model. A regression with constant gives a reduced coefficient but is still significant (p<0.001). This relationship holds for all dorsally retouched flakes in our sample. Hiscock and Attenbrow (2003) have established equally strong correlations between the proportion of the flake perimeter that was retouched and the Average Kuhn reduction index. These relationships exist because the values of all these variables (i.e. Average Kuhn reduction index, length of retouch, and proportion of flake perimeter) are higher on more heavily retouched specimens.

<table>
<thead>
<tr>
<th>McCarthy’s type</th>
<th>Bondaian</th>
<th>Capertian</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burin</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Core</td>
<td>8</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Elouera</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Knife</td>
<td>6</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Saw</td>
<td>3</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Scrapers</td>
<td>46</td>
<td>26</td>
<td>72</td>
</tr>
<tr>
<td>Unlabelled</td>
<td>47</td>
<td>20</td>
<td>67</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>112</strong></td>
<td><strong>56</strong></td>
<td><strong>168</strong></td>
</tr>
</tbody>
</table>

We tabulate the typological categories of specimens in our sample of retouched flakes.

![Figure 2](Image)

**Figure 2. Illustration of a retouched flake from Capertee 3 (ESP1024, Square 9 Level G), showing the measurement of retouch intensity.** The Average Kuhn reduction index is calculated as \( (t_1/T_3 + t_2/T_2 + t_3/T_1)/3 \).

If the length of margin that was retouched increased as reduction proceeded then at least the aspects of McCarthy’s classification that are based on the number of retouched edges are likely to vary with the extent of reduction. To evaluate this proposition we also measured the amount of retouch by recording the number of locations on which retouch occurs on the sample of complete retouched flakes. We recorded the presence or absence of retouch in eight notional sections (proximal end, distal end, and for each margin the proximal, medial, and distal thirds). Each implement could have between one and eight of these sections retouched. The number of retouched sections shows a strong linear relationship with the Average Kuhn reduction index (\( r = 0.86 \), d.f. = 151, p<0.001), such that the extent of reduction expressed by the Kuhn index explains more than 74% of variation in...
the number of retouched sections. This pattern is congruent with the hypothesis that as reduction proceeds additional sections of the flake margin are retouched. Hiscock and Attenbrow (2003) have also shown that in the Capertee assemblage the expansion of retouch around the perimeter of a flake proceeded in a regular way: often starting with blows to the distal portion of the left lateral margin and/or distal end, and spread to other sections of the flake as reduction progressed. This explains why the specimens that McCarthy described variously as side scrapers or end scrapers have low Average Kuhn reduction indices.

Increased retouching that lengthens the retouched edge and involves retouching a second or third margin is likely to also change the curvature of the retouched edge. This prediction can be evaluated with a simple quantitative measure of retouched edge shape obtained by the calculation of an ‘Index of retouch curvature’\(^1\). This index is created by using the equation \((R_6 / R_3)\), which expresses the depth of concavity or convexity of the retouched edge in millimeters (a value labeled \(R_6\)) relative to a notional ‘baseline’ represented by a straight line between the ends of the retouch, the length of which was measured in millimeters (a value labeled \(R_3\)). These dimensions were measured in the plane of ventral surface, as illustrated in Figure 3, with a retouched edge protruding beyond the \(R_3\) line being given a positive \(R_6\) value while a retouched edge retreating from the \(R_3\) line being given a negative \(R_6\) value. Measured in this way the ‘Index of retouch curvature’ is 0 for a straight edge, negative for concave edges, and positive for convex edges. The larger the positive value the more convex is the edge. For the Capertee assemblage this index ranged from a slightly concave value of -0.19 through to highly convex value of 13.42, with most specimens being slightly or moderately convex (\(\overline{x} = 0.34, \text{s.d.} = 1.15, N = 154\)). The positive relationship between this index of flake shape and the extent of reduction can be evaluated in several ways.

Two illustrations of this connection between retouch curvature and reduction are provided by the box plots drawn in Figure 4. Median values, upper quartiles and most lower quartiles of the retouch curvature index consistently increase with higher categories of the Kuhn index (Figure 4A). A strong linear correlation exists between the retouch curvature index and the Average Kuhn reduction index \((r = 0.77, \text{d.f.} = 150, p<0.001)\). This measurement indicates the extent of reduction explains more than 60% of variation in shape of the retouched edge as we have measured it. A similar pattern is revealed in the progressive increase in median and upper quartile values of the retouch curvature index as the number of retouched sections increased (Figure 4B).

Correlation statistics of the number of retouched sections and the curvature of the retouched edge also indicate a significant positive relationship, as calculated using Spearman’s rho \((r_s = 0.523, \text{d.f.} = 151, p<0.001,\) and Pearson’s \(r = 0.544, \text{d.f.} = 151, p<0.001\).

All of this evidence is consistent with the reduction model described above, demonstrating that not only are there morphological continuums within this assemblage but also that this pattern displayed by the assemblage is best explained in terms of the extent of knapping each specimen has undergone. For the Capertee 3 assemblage we can offer the following normative depiction of the reduction process that resulted in the dorsally retouched flakes. Retouch, beginning in a restricted area of one margin, typically produced a slightly concave or convex edge, but as reduction proceeded and retouching was carried out on adjacent margins of the flake the retouched edge became progressively more convex until semi-discoidal specimens retouched on three or four margins were produced. This progression of retouching is illustrated in Figure 5, which uses values predicted in the regression analyses discussed here to give an inferred interpretation of the typical morphological changes that would have taken place as reduction proceeded.

We therefore conclude that variation in the location of retouch and the shape of retouched edges is largely

---

\(^1\) In two previous publications (Hiscock and Attenbrow 2002, 2003) we have employed the Index of retouch curvature exactly as described here but inadvertently and incorrectly gave the calculation as \((R_3 / R_6)\). The equation and description of procedure provided here is the correct one.
Figure 4. Box plots illustrating the positive relationship of the retouch curvature index to two measures of the extent of reduction: A = Average Kuhn reduction index, and B = Number of retouched sections.

Figure 5. Illustration of typical reduction continuum inferred at Capertee 3. (A) has Curvature Index of 0.15 and Reduction Index of 0.38, (B) has Curvature Index of 0.27 and Reduction Index of 0.65, (C) has Curvature Index of 0.38 and Reduction Index of 0.74, and (D) has Curvature Index of 0.57 and Reduction Index of 0.92.

Explicable in terms of the extent of reduction undertaken on specimens. Since shape and extent of retouch is the basis McCarthy used in classifying implements into different types this inference reveals that the difference between many of the McCarthyian types merely reflects different amounts of reduction. The implication of this conclusion for functional interpretations of scraper morphology is potentially dramatic, and is worth exploring further.

Changes to the Retouched Edge Associated With Reduction

In addition to the inference that can be drawn from the above, that the continuous morphological variation in these dorsally retouched flakes from Capertee 3 is largely a reflection of the different amounts of reduction to which specimens have been subjected, there are also many specific characteristics of the retouched edge that are clearly related to the extent of retouching. Reduction-related changes for a number of these edge characteristics on complete dorsally retouched chert flakes are summarised in Figure 6, using a common graphical system. In these diagrams the vertical bars denote the 95% confidence interval for mean in each 0.2 increment of the reduction index, the node on each bar marks the arithmetic mean, the stippled envelope encloses the 95% confidence interval for categories of reduction index, and the broken line illustrates the median trend line. Expressed graphically in these ways the differences in typical values between the five 0.2 categories of the reduction index trace obvious trends in edge characteristics as reduction proceeds. The key trends identified can be summarised as follows.
Lateral expansion of retouched edge

As we have already discussed, the retouched edge expanded laterally around the margins of the flake as retouching continued. This expansion can be measured by counting the number of sections retouched around the circumference of each specimen. As retouch expands around the margin the count of retouched sections is increased. Consequently the measurement of the average or median number of retouched sections per 0.2 category expresses the lateral extent of retouching for each phase of reduction, and as revealed in Figure 6a there is a consistent increase in the relative length of retouch as reduction continues. As retouch expands the retouched edge becomes increasingly convex in plan shape, as discussed earlier. This trend is illustrated in Figure 6b.

Figure 6. Illustration of the relationship between selected morphological characteristics and the Average Kuhn reduction index for complete chert dorsally retouched flakes (scrapers). The characteristics are A) Number of retouched sections per specimen, B) Retouch curvature index, C) Average retouch angle, D) Range of average retouch angles, E) Percentage of the retouched edge that was notched, and F) Average depth of notches. Vertical bars denote the 95% confidence interval for mean in each category of the reduction index. The node on each bar marks the arithmetic mean and the envelope encloses the 95% confidence interval for categories of reduction index. The broken line illustrates the median trend line.
These changes during reduction, from short and straight or concave retouched edges after a small amount of retouching to long and convex edges after extensive retouching, create the pattern that has already been depicted in Figure 5.

Alteration of Edge Angle

Average edge angle increases during the early and middle phases of reduction, as expressed in the Kuhn index, until retouched edges are typically quite steep, often being close to or exceeding 80° (Figure 6c). Increased edge angles were commonly associated with greater frequencies of abruptly terminated flake scars on the retouched edge. Average edge angles then decline during later phases of retouching, eventually reaching values nearly as low as those at the beginning of the retouching process. This reversal of the trend in edge angles can largely be explained as the result of changed knapping practices later in the retouching sequence, effectively rejuvenating the edge and enabling reduction to continue with a lower probability of creating abrupt terminations or breaking the specimen. Rejuvenation was accomplished by striking thicker, wider flakes from the retouched edge. As reduction continued the range of angles exhibited by retouched edges becomes larger, as some edges and sections of edges are rejuvenated while others are not (Figure 6d).

![Graph showing the percentage of notches by category](image)

**Figure 7. Changes in the frequency of simple and complex notches during reduction.**

Edge Shape

One consequence of the shift to removing larger flakes later in the retouching sequence is the change in the shape of the retouched edge. Several trends in the plan shape of retouched edges are apparent as reduction proceeds. One pattern already discussed is the increasing curvature of the edge that usually accompanied expansion of retouching around the flake perimeter. Although the extension of retouching around the flake circumference means that more extensively retouched specimens have convex edges, there may be straight or even concave sections along the length of the generally convex edge. One way to express such differences in the edge shape is by measuring the characteristics of ‘notches’, concave retouched areas arbitrarily defined as concavities in the retouched edge wider than 10mm. Figure 6e illustrates that as a percentage of retouched edge notching is relatively common at the start of the retouching process, becomes comparatively rare as reduction proceeds, but again becomes more common in extensively retouched specimens. The increase in notching later in the retouching sequence is partly a result of the creation of more notches but also a result of the creation of different kinds of notches. Late in the reduction process notches are both wider and deeper (Figure 6f) than those produced when retouching is initiated on a flake. These large notches are typically created by the removal of a single large flake. This is revealed in Figure 7 which shows that simple notches (ie. concavities produced by single flakes) are the dominant kind of concavity in heavily retouched specimens, whereas complex notches (ie. concavities produced by multiple flakes) were the only ones created when retouching commenced. The production of simple notches occurred when blows were placed relatively far from the edge and removed longer, slightly more invasive, and wider flakes – flakes that were effective in removing step terminations and lowering edge angles.

Reduction Continuums and Tool Use: Alternative Models

Evidence we have presented in this paper indicates that the reduction model outlined earlier, in which there is a positive relationship between morphological characteristics such as the curvature of retouched edges and the amount of retouching, can be extended to explicate many of the edge features that have frequently been taken to indicate artefact function, such as angle of retouch, shape of retouched edge and nature and abundance of notching. As discussed above morphological differences between specimens in characteristics of edge length, shape and angle have often been interpreted as reflections of functional differences. However, it has been shown that for the Capertee assemblage the length and shape of retouched edges, the angle of retouch scars on those edges, and the nature and frequency of notches are all changed as retouching proceeded. These characteristics are not independent of, but are intertwined with, the amount of reduction. (Intriguingly this conclusion echoes earlier observations of the relationship between reduction and edge angle in Australian assemblages – see Hiscock 1982a, 1982b, 1983).

In light of this inference we note the more obvious models that might describe the relationship between changing artefact morphology and artefact use. Each of these models can be appraised as follows:
However, regularity in reduction related morphological change between specimens would probably create complications for stone users in a number of ways if they insisted on performing tasks with specifically suited edges. For example, in order to have tools available for a large range of tasks foragers might need to transport a collection of specimens representing different levels of reduction or else risk wasting edges of a specimen by retouching it until the morphology suited the task at hand. The strategy that might be effective would at least partly depend on the rate at which particular categories of edge morphology occurred during the reduction sequence. In the case of the Capertee 3 pattern presented here, in which edge angles typically oscillated from medium to steep and back to medium during reduction, it would have been easier to obtain medium angled tools (say 55-70°) than ones with higher angles (say >75°). If these patterns of edge characteristics and specimen size and morphology are directly related to the technology of reduction, as we have argued them to be, and prehistoric foragers insisted on a specific form for each kind of task, then we would be in the curious position of being obliged to argue that the nature and/or timing of activities of a foraging group (at least those involving stone tools) were constrained or determined by the stoneworking technology. The idea that reduction strategies shaped functional options available to prehistoric groups is unlikely to be a popular conclusion amongst archaeologists, but at least in those assemblages in which morphological variation is explicable as a technological byproduct of reduction the question researchers must pose is: “what explanatory power can concepts of tool design and tool efficiency provide”?

In this model use-wear and residues studies of discarded artefacts may not be capable of providing a reliable indication of the tasks for which those artefacts were used. This difficulty reflects two processes connected to flake retouching. Firstly, the retouching of used edges removes much evidence of use. Secondly, the change in function as reduction progressively creates different morphologies means that the use evidence on the discarded specimen is not indicative of uses of the specimen earlier in its history; a principle clearly enunciated by Frison (1968). Consequently use analyses that examine a small number of discarded retouched flakes should be interpreted with care, and inferences about site functions based on those analyses should be regarded with considerable skepticism. Use wear and residue studies must not only seek to employ large samples, irrespective of the large labour costs incurred, but must also measure the nature of functional change associated with reduction. The latter goal could be accomplished through methods such as use studies of flakes conjoined onto implements and/or by studies of samples with small, medium and large values of Kuhn’s reduction index.

**Model 2: Artefact use remains unchanged during reduction.** This hypothesis avoids the complications inherent in Model 1 by predicting that despite morphological changes during reduction the knapper is able to continue using the specimen for the same activities. Such a model would at first sight appear to make sense of artefact resharpening: implying that continued retouching served merely to extend a specimens’ duration of use, without requiring that the nature of the use must change. However, the unchanged use of specimens despite substantial alterations to edge angle, edge length and edge shape must signal the unimportance, perhaps even irrelevance, of morphology for function.

This principle might operate in a number of ways. For instance, it might be that edge characteristics are not a fundamental determinant of the uses to which a specimen can be put, because on specimens with edges containing a variety of shapes the artisan can sufficiently manipulate the orientation of the tool, angle of contact with worked material, and motion of tool so that a wide range of tasks can be accomplished. This hypothesis, that almost any edge may be used for any purpose, is not consistent with the traditional conclusion of many functional studies, and while it is testable is unlikely to be generally applicable.

An alternative possibility is that edge characteristics are important for the efficiency of any particular use,
with specific edge angles and edge shapes being more effective and efficient for some tasks than others, but that efficient tool use was not critical for the performance of a task. This principle would mean that there is indeed a theoretical association between use and the edge characteristics best suited to the task, but that sadly covariation between implement forms and kinds of uses would often be very poor, simply because the user of the implement continued to use the specimen in the same way even when its morphological characteristics had changed to a less suitable state. The implication of unchanging patterns of use through a reduction sequence even though the edge characteristics at any particular point in the sequence were efficient for one use and not others would logically be that prehistoric tool users were prepared to employ inefficient tools.

The level of inefficiency represented by tool use in any assemblage might usefully be evaluated experimentally, and may also be a noteworthy feature in the construction of models explaining the selective context in which any foraging group was operating. For instance, this kind of functional inefficiency may be a cost worth paying for foragers who cannot predict the nature and timing of activities, and for whom multi-functionality confers substantial benefits (see Hiscock in press b). Additionally, in locations far from replacement raw material the cost of employing inefficient, even barely functional, tools may be outweighed by the benefits gained from conserving the stone material at hand. This notion of tool inefficiency being a strategy for raw material conservation raises the possibility that within any region the inefficiency of tool use may vary spatially, becoming more pronounced as distance to source and other economic factors make tool replacement more expensive.

Yet another example of how the identification of this kind of form-function relationship might be informative is in debates about the selective advantage of one group over another. For instance when comparing chronological change between technological systems emphasizing extended tool resharpening and potential (see Shott 1996) and one with short-lived specific tools, a comparison often suggested for the Middle- to Upper-Palaeolithic transition, this issue of tool inefficiency might be critical in developing explanations of group success.

- **Model 3: Artefact use is minimal.** This third model posits minimal use of retouched specimens, perhaps with use taking place only towards the end of the reduction process. In this model the variety of morphological states within the reduction sequence would be explained by a purpose other than resharpening of a blunt working edge. The implication of such a pattern is that use occurred at only one phase in the history of a specimen, perhaps when the object was already shaped to a specific form, and that extended use requiring resharpening did not take place. This, of course, was the proposition underlying the conventional notion of implement types as being designed as functionally proficient tools, and this model is incompatible with the arguments advanced by Dibble and others that resharpening is a primary role for retouching. Alternatives to this traditional idea of implement types exist, such as the proposition that flake retouching was frequently unsuccessful in creating functionally suitable edges, and consequently specimens were not used during much of the mass removal achieved by retouching. Irrespective of which mechanism was in place the question raised by any variant of this model is why it was cost-effective to expend so much stone material for a minimally used tool. In some senses this model is one of wasteful tool production, representing a strategy which would be effective when raw material conservation was a minimal concern and other factors more powerful stimulants.

These three models describe the inability of stoneworkers to conserve stone by extending the use of a tool through retouching while also using each tool for a specific function and having that tool operate in an efficient way throughout its entire use-life. For the reasons provided here it may not be possible for a knapper to create tools that satisfy all of these qualities, and knapper’s may have to choose between the models discussed here.

In constructing these models it is not our intention that they be perceived as competing universal explanations. We can see no reason that each model might not be applicable in some situations but not others, and might therefore represent alternative strategies. We suggest that these models therefore represent structural differences in the articulation of tools and production systems, and it is therefore conceivable that one model might describe the typical form-function relationship in one region but not in another. Furthermore, all three models may be represented in a single behavioural system, although the relative emphasis on any one approach may indicate the strategies being emphasized by any foraging group in response to local economic circumstances. If that is a reasonable summary of the status of these models it becomes imperative to test the relationship between use and artefact morphology in each assemblage, rather than presume universal relationships exist. This would require that use evidence be studied in the context of a technological analysis of the reduction process.

**Conclusion**

Our hope is that this paper will stimulate more extensive discussions of the articulation of artefact production and use, and provoke more sophisticated conceptualization of tool use and toolkits. We have advocated the need to move beyond the naive presumption that conventionally recognized implement types have a simple association with particular uses and that by implication those types
must have been designed to be optimal in the particular use to which they were constructed. The fundamental issue we have raised is the contradiction that exists between two central principles in modern interpretations of lithic assemblages. On the one hand researchers investigating implement function have frequently had an expectation of a distinct form-function relationship, usually expressed as a distinct relationship between the angle, shape and edge of retouch. On the other hand researchers investigating the technology of implement production have increasingly theorized, and sometimes demonstrated, the progressive alteration of implement form. Tension between these two seemingly incompatible propositions creates an interpretative paradox: “how can implements be designed for, and be efficient in, a specific use if their morphology is continuously changing?” Future studies should actively pursue issues that may help answer this question, such as experimental and archaeological investigations into the differential efficiency of tool forms, quantification of the nature of morphological change during artefact reduction, and the evaluation of the relationship between use evidence and the reduction process. We have formulated and discussed three models of this relationship, and the testing of these models in specific archaeological assemblages will represent an initial step in understanding the interaction between past reduction continuums and tool use.

Acknowledgments

We thank Chris Clarkson and Lara Lamb for the invitation to include our paper in this significant volume. The Capertee collection is housed at the Australian Museum in Sydney, and we thank the Trustees of the Australian Museum for access to the material. Artefact recording was carried out during September 2000, October 2001, February 2002, July 2002, October 2002 and November 2002 at the Australian Museum, which provided laboratory space and facilities. We acknowledge the assistance of Leanne Brass in organising access to the collection. Chris Clarkson, Lara Lamb and Oliver McGregor provided valuable comments on drafts of this paper. Finally, we thank Chris Clarkson for drawing Figure 5.

References


Ferguson, W.C. 1980 Edge-angle classification of the Quinup Brook implements: testing the ethnographic analogy, Archaeology and Physical Anthropology in Oceania 15:56-72.


Brisbane: The University of Queensland.