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

Chris Clarkson

School of Archaeology and Anthropology, Australian National University, Canberra, ACT 0200, Australia

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Archaeologists are increasingly in need of quantitative measures of stone artefact retouch. Existing techniques fail to provide a generic measure of retouching for all chipped stone artefacts. A fast and reliable index is proposed which measures retouch in terms of the invasiveness of flake scars on the surfaces of complete stone artefacts. Unlike other measures, the index of invasiveness is well suited to the analysis of bifacially worked artefacts such as bifacial points and bifaces. Experimental tests demonstrate a strong correlation between the index and measures of reduction based on diminishing flake weight and numbers of retouch blows. Inter-observer reliability is also demonstrated through the use of a blind test. Limitations of the method are discussed, although potential techniques for surmounting problems are identified. An archaeological application of the index demonstrates the utility of the method in the context of regional assemblage variability in northern Australia.

Keywords: STONE ARTEFACTS, CURATION, BIFACIAL TOOL REDUCTION, EXPERIMENTAL FLINTKNAPPING, NORTHERN AUSTRALIA.

Introduction

Archaeologists are increasingly asking questions concerning the extent to which different stone artefact assemblages have been curated. This is because assessments of relative curation are useful in testing models of changing mobility, land-use, economy, and technological organization, as well as in defining the relationships between tool design, labour investment and morphological standardization (for discussion of the value of the curation, tool design and use life concepts in addressing these questions see Ammerman & Feldman, 1974; Bamforth, 1986; Binford, 1979; Bleed, 1986; Close, 1991; Davis & Shea, 1998; Dibble, 1984, 1995*a*, 1995*b*; Gordon, 1993; Hayden, Franco & Spafford, 1996; Hiscock, 1994, 1996, 1998; Kelly, 1988; Kelly & Todd, 1988; Parry & Kelly, 1987; Holdaway, McPherron & Roth, 1996; Kuhn, 1990, 1992, 1995; Nash, 1996; Neeley & Barton, 1994; Nelson, 1991; Odell, 1996; Shott, 1989, 1996; Roland & Dibble, 1990; Torrence, 1983, 1989).

Our ability to address such questions adequately relies on having effective quantitative measures of stone artefact reduction, curation and use-life. It has been argued (Barton, 1988; Kuhn, 1990; Davis & Shea, 1998; Dibble, 1984, 1995*a*, 1995*b*) that measurement of the amount of retouching present on tools provides one such means of addressing the relative curation and use-life of artefacts in different archaeological contexts. Generating such a metrical index of stone tool reduction for each artefact in an assemblage would provide the necessary data for making comparisons of relative retouch intensity and tool curation in different spatial and temporal contexts. In addition, metrical data in the form of a reduction index would allow the comparison of not only the level of reduction of different assemblages, but also provides a measure of the degree of variation in retouching within and between assemblages.

Finding appropriate measures of variation allows for better integration of emerging theoretical concerns for the characterization of variability within and between populations, with the types of archaeological materials under analysis (O'Brien, 1996; Maschener, 1995; Telster, 1995; Barton & Clark, 1997). The index of invasiveness outlined in this paper provides one such means of quantifying variation in artefact retouch and reduction that is quick, versatile and relatively robust.

This paper first examines the limitations of several existing measures of artefact retouch before explaining various theoretical and methodological aspects of the index proposed here. Theoretical expectations are then verified against experimental data derived from the hard-hammer retouching of 30 flakes of varying size, shape and raw material type. This experiment successfully demonstrates a correlation between the index of invasiveness, amount of retouch and flake weight. Inter-observer error is then examined using a simple

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blind test designed to quantify the degree of error between recordings of the index by ten different archaeologists for the same ten artefacts. Finally, the utility of the index is demonstrated through its application to archaeological assemblages in northern Australia. This example demonstrates the potential of the technique to quantify increasing levels of retouch as flakes are transported away from a chert quarry.

Quantifying Stone Artefact Retouching

Several techniques for the quantification of stone artefact retouch have been proposed in recent years (Barton, 1988; Close, 1991; Dibble, 1995*a*; Kuhn, 1990; Dibble & Pelcin, 1995; Davis & Shea, 1998). Unfortunately, limitations and problems associated with each of these methods severely restricts their application to archaeological assemblages.

Perhaps the simplest means of quantifying stone artefact retouch is the measurement of the length of retouched margins (Barton, 1988) and the depth of retouch (Barton, 1988; Close, 1991). However, while these measures may be of use for many analytical purposes, results for individual artefacts and assemblages are not strictly comparable due to the effects of variation in artefact size. While such measures could be considerably improved by calculating extent as a percentage rather than an absolute measure, this approach appears to have been rarely adopted. Both of these measures also fail to provide a description of the distribution of retouch over the surfaces of an artefact. As extremely simple techniques they are also unlikely to accurately parallel absolute measures of reduction, such as investment of time or effort, or the loss of original mass or volume.

Kuhn's (1990, 1995) geometric index, on the other hand, is a more sophisticated quantitative measure of flake margin attrition. Kuhn's index calculates the ratio between retouch height and flake thickness, expressed as a figure between '0' and '1'. A serious limitation of this index, however, is that it is restricted to the unifacially retouched flakes in an assemblage only. Kuhn's index is unable to measure extent of bifacial retouch due to its reliance on the relationship between original flake thickness and edge angle; both of which may be substantially altered by bifacial flaking. Furthermore, although Kuhn's index generates a metrical result that increases with continued retouching, the rate of increase is sensitive to variation in the cross-sectional shape of flakes. As Kuhn concludes in his paper, the ultimate importance of the index is in providing an uncalibrated measure of retouch intensity. Thus, while Kuhn's index is a useful measure of unifacial reduction, it is incapable of providing a generic index of stone artefact retouch.

A different approach to quantifying flake reduction was explored by Davis & Shea (1998). Davis and Shea attempted to apply Dibble & Pelcin's (1995) equation for the prediction of original flake mass from two variables, platform thickness and platform angle, to calculate the loss of weight a specimen had sustained through modification. Unfortunately, in applying Dibble and Pelcin's predictive equation to their own "realistic", experimentally produced flakes, Davis and Shea were forced to "caution against applying this predictor to archaeological assemblages" (Davis & Shea, 1998: 607) due to the unquantified effects of platform width and termination type (among other variables) on flake mass. It remains possible that Dibble and Pelcin's equation, if further developed (cf. Dibble, 1998; Pelcin, 1997, 1998; but see Shott *et al.*, 2000), will become an important estimator of flake reduction once estimates of original flake weights can be shown to lie consistently within acceptable error margins. Archaeological assemblages may yet prove the most useful materials on which to develop these principles, given that they preserve an image of not only the underlying relationships but also the complexity and variation that occurs in non-laboratory circumstances (Hiscock & Clarkson, 2000).

Finally, Dibble (1991, 1995*a*, 1995*b*) proposed an index of reduction which measures retouching in terms of the amount of surface area removed from a flake. This technique calculates the ratio between platform area (platform width times thickness) and ventral area (length times width) (a similar index employing surface area and thickness was also proposed by Holdaway, 1991). Dibble's technique has the advantage of standardizing results for artefact size and is also theoretically applicable to wide variety of complete flakes. Although Dibble demonstrates a significant correlation between platform area and flake area for assemblages from Europe and the Levant, of concern is the degree of variation expressed in this relationship (see also Dibble, 1997: 156). This seriously questions the accuracy of the technique for calculating the extent of retouch on individual artefacts. It is conceivable, for instance, that in some cases the variation in the ratio for unretouched flakes could entirely overlap that of retouched flakes. It would appear therefore that this technique is likely to be of greatest utility only in cases where a high degree of standardization in blank form can be demonstrated.

In summary, this section has drawn attention to problems that have undermined previous attempts to quantify the amount of retouch on stone artefacts. In the following section an alternative index is proposed which attempts to resolve these problems while also providing an accurate and robust measure of retouch intensity.

An Index of Invasiveness

As an alternative to the approaches reviewed here, this paper presents a technique for the measurement of the extent of retouch on both unifacially and bifacially

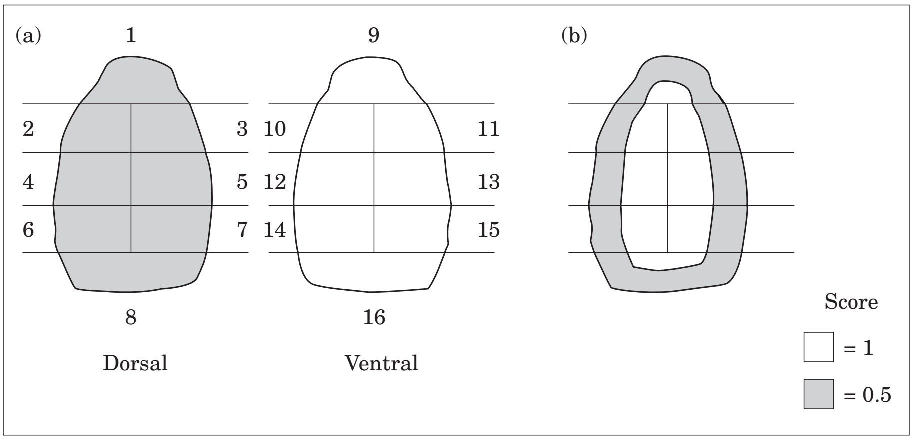

Figure 1. Method for dividing the dorsal and ventral surfaces of artefacts into segments and zones. (A) Method for dividing artefacts into 16 analytical segments. Segments could also be labelled: 1. dorsal proximal end, 2. dorsal left proximal, 3. dorsal right proximal, 4. dorsal left medial, 5. dorsal right medial, 6. dorsal left distal, 7. dorsal right distal, 8. dorsal distal end; with equivalent ventral labels for numbers 9–16. (B) Method for dividing artefacts into different invasiveness zones. Values of '0·5' are given to segments in which retouch scars are contained within the grey zone. A value of '1' is given when scars extend into the inner white zone of the artefact. Segments without retouch have a value of '0'.

retouched flakes and bifaces. This technique provides a generic measure of the *invasivness* of retouch for any artefact exhibiting flaking directed from the lateral margins toward its centre. This index differs from measures that have attempted to quantify retouch in terms of length, loss of original mass, surface area or changing flake geometry. Instead, it provides a measure of the extent to which retouch scars cover the surface of an artefact. Although the focus of this index is on flake scar distribution rather than artefact weight or edge loss, it is nevertheless demonstrated experimentally that an increase in the index of invasiveness corresponds closely to decreasing artefact weight.

Measurement Procedures and Predicted Results

Measuring the invasiveness of retouch flake scars on a specimen could be achieved in many ways, including simple estimation of percentage coverage (cf. Marcy, 1993), quantification using computer image analysis, measurement of flake scar invasiveness toward the medial point of an artefact, or some combination of these techniques. Each technique would produce a numeric result that may be satisfactory to differing degrees for different analytical purposes. Mere estimation of retouch coverage, would for instance be the quickest procedure, but also prone to the greatest error. The use of currently available computer software on the other hand would provide very high accuracy, but the time involved in acquiring an image of both sides of an artefact, defining the surface area and then the area of retouching is considerable. The third possibility involving some kind of manual measurement of the percentage encroachment of flake scars toward a central point, is equally feasible, but accurate results would necessitate taking many measurements for a single artefact. A fourth option involving a combination of estimation and numeric expression is presented in this paper. This approach involves translating estimations of the invasiveness of retouching at many points on an artefact, into a numeric index of retouch coverage. This has the advantage of speed, as no actual measurements are taken, and a high level of accuracy, as estimations are broken up into numerous individual sections before being totaled to give an estimate of retouch scar coverage.

To employ this technique, a simple system is presented which allows fast and accurate calculation of flake scar coverage for both surfaces of an artefact. An artefact is first conceptually sub-divided into eight analytical segments on both its dorsal and ventral surfaces (Figure 1(a)), giving a total of 16 segments to an artefact. Sub-divisions are made such that each segment represents one-fifth (20%) of the total length of the artefact. The artefact's surface is then further divided into two zones for each segment—an outer zone and an inner zone (Figure 1(b)). For the inner six segments (segments '2–7' and '10–15'), invasiveness zones are partitioned at the halfway point between the middle and the lateral margin of the artefact. For the proximal and distal segments (segments '1', '8', '9' and '16'), the marginal/invasive boundary is located halfway between the distal or proximal margin of the flake and the outer edge of the inner six segments.

Each zone is ascribed an invasiveness score, representing the maximum degree of encroachment of retouch scars onto the artefact's surface (Figure 1(b)). The outer zone, or marginal zone, is ascribed a score of '0·5', indicating penetration of flake scars not more than halfway to the central point of the flake. The inner zone, or invasive zone, is given a score of '1', indicating that retouch scars terminate more than halfway from

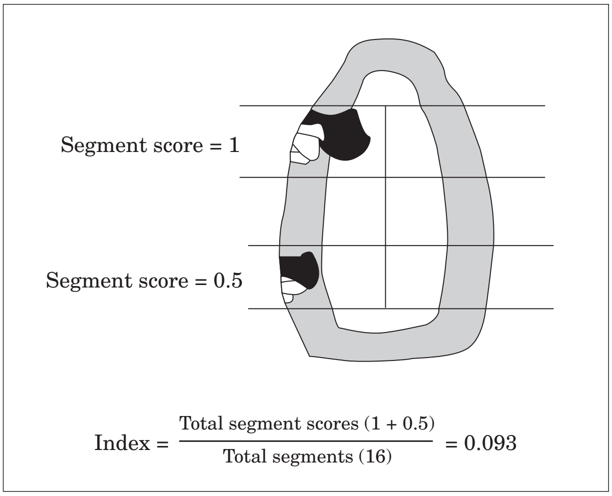

Figure 2. Diagram showing the correct application of the index of invasiveness based on the maximum encroachment of flake scars in two segments.

the lateral margin and are approaching the medial point of the flake. Scores are attributed on the basis of the maximum encroachment of flake scars in each segment (Figure 2). These scores may then be summed to give a total figure for the invasiveness of each artefact. Dividing this total by the number of segments (i.e. 16), gives a result ranging between '0' (no retouch) and '1' (completely retouched) (Figure 3). Thus the formula for calculating the Index of Invasiveness is:

$$\text{Index of Invasiveness} = \Sigma S_s/16$$

Where ΣS_s is the summed total of segment scores.

Sub-dividing specimens in this way allows for 156 possible combinations of the scores '0', '0·5' or '1', and generates 33 different index results. These results increase in increments of '0·3' with the exception of four cases where results increase by '0·4'. Figure 4 presents a frequency distribution of the number of possible combinations returning a specific index result. From this diagram it can be seen that the values '0' and '1' occur only once, whereas values approaching '0·5' from either end of the scale occur with increasing frequency. The spread of index results is also symmetrical from either end of the scale. This pyramid-like distribution occurs because only single combinations will generate the result '0' (i.e. will occur only when all segments equal '0') or '1' (i.e. will occur only when all segments equal '1'). The number of combinations resulting in an index score greater than '0' or less than '1', on the other hand, increases as the index approaches '0·5'. This merely reflects the range of different possible invasiveness scores that may be spread across the 16 segments.

In application, the index should only ever increase with increasing retouch. This is because scars, once added to an artefact, cannot be removed without adding new scars. Even in cases where the entirety of a scar is removed from one surface by way of a blow directed from that surface onto the opposite surface, it must be replaced by a scar (or scars) of equal or greater size on the opposed surface. In theory then, the index of invasiveness should have the capacity to measure increasing retouch intensity as a factor of increasing invasiveness of retouch. It also follows that because mass is removed from an artefact with continued retouching, a correlation should exist between increasing index of invasiveness and decreasing flake weight.

Experimental Test of the Index of Invasiveness

With these principles in mind, it is possible to demonstrate the operation of the index of invasiveness by experimentation. A simple experiment was designed to record the index of reduction at intervals of 10 blows throughout the hard hammer retouching of 30 experimentally produced flakes. The weight of specimens was also recorded after each set of 10 successful flake detachments so that the relationship between the index and flake weight could be monitored. A successful flake detachment was defined as a flake measuring greater than 3 mm in length.

The sample of flakes used in the experiment consisted of a wide range of sizes, shapes and raw materials (Table 1). This variety was deliberately chosen to simulate the diversity of an archaeological assemblage and to test the robusticity of the index as a generic measure of retouching and reduction for a wide range of cases. The raw materials used in the experiment included obsidian ($N=7$), chert ($N=9$), flint ($N=3$), quartzite ($N=2$), mudstone ($N=6$) and silcrete ($N=3$), with the weight of flakes ranging from 22·3 g to 143·8 g. A single silcrete hammerstone weighing 308 g was employed throughout the experiment without substantial alteration to its surface or weight.

The experimental retouching of flakes was carried out in a non-standardized fashion by the author in order to create a range of results and to simulate a range of possible reduction sequences. Retouching continued until specimens were completely covered by flake scars, until they broke, or until flakes could no longer be detached using free hand percussion.

Results

One test of the technique is to examine the relationship between the index and the amount of retouching delivered to an artefact. It was stated above that because flake scars may only be added to a flake and not removed without adding new scars, the index should increase as the amount of retouching increases. To test this prediction experimentally, the index of invasiveness is plotted after each interval of ten blows, expressed as the percentage of the total number of retouch blows delivered to each flake (Figure 5(a)).

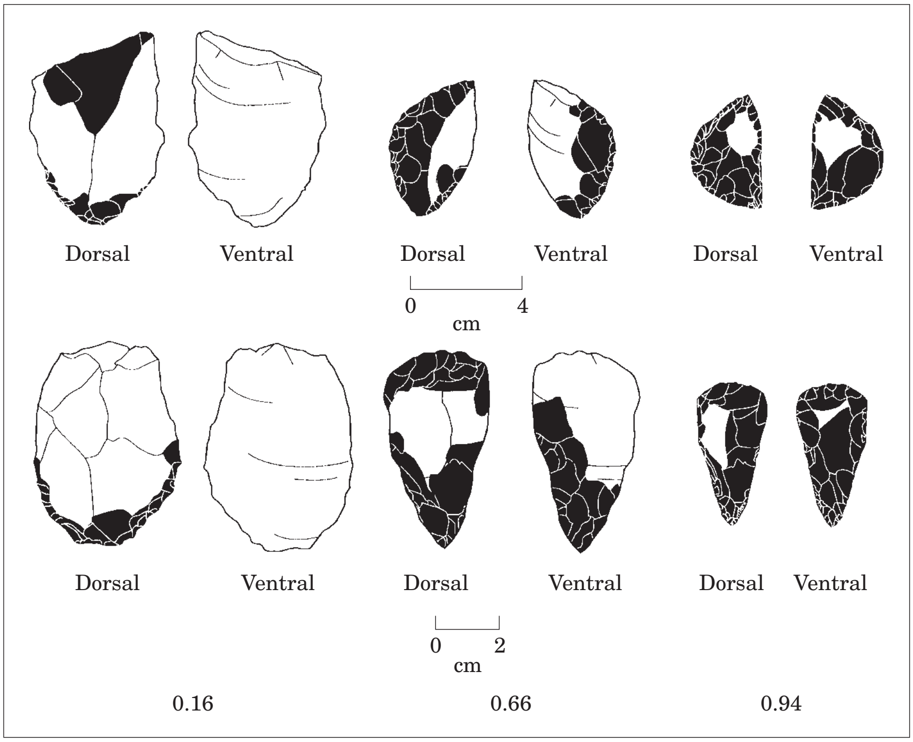

Figure 3. Examples of index values for experimentally produced flakes. Dorsal and ventral views are shown for two flakes at three stages of reduction, represented by the index values 0·16, 0·66 and 0·94.

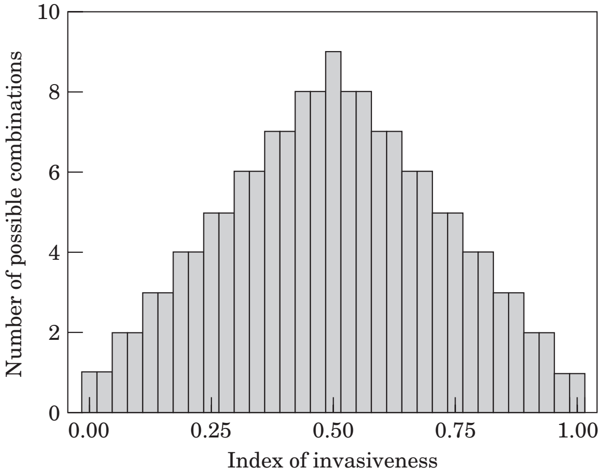

Figure 4. Theoretical values of the index of invasiveness returned for all possible combinations of marginal and invasive flaking across the 16 segments of an artefact.

Raw materials are divided on the basis of granularity into high quality (obsidian, flint and chert) and low quality (quartzite, mudstone and silcrete) in order to assess the effects of different flaking properties on the performance of the index.

The results of this first test show a strong relationship between increasing retouch and increases in the index of invasiveness (Figure 5(a)). This relationship is curvilinear and shows a slight expansion in the distribution of index values toward the centre of the curve. It is also apparent that raw material properties do not affect the performance of the index when measured against amount of retouching. The downward tilt in the curve can be successfully removed via a square root transformation of the x axis, creating a strongly linear (r^2=0·982, y=85·83x+11·07) and highly significant (F=2140·7, P=0·0005) relationship between increasing index values and increasing retouch (Figure 5(b)).

The curvilinear nature of the trend depicted in Figure 5(a) can best be explained as the result of a slowing of the rate at which segment scores increase over the sequence of reduction. This effect is understandable given that new scars may be added over the top of old scars without necessarily increasing the invasiveness of each segment, and that this will occur with increasing frequency as flake scars begin to cover a stone artefact.

Increasing variation in the middle part of the reduction sequence, on the other hand, may be partly explained as the effect of the rotation of flakes (i.e. turning the flake over to retouch the other side) on the rate of index increase. Rotation increases variation simply because adding scars to a new surface may reduce the size of scars on the previous surface—in effect “demoting” existing segment scores (i.e. from ‘1’ to ‘0·5’ or from ‘0·5’ to ‘0’) and creating “flat spots” in the curve. This creates a tendency for results to fall to

Table 1. Summary of attributes for the flakes employed in the reduction index experiment

Specimen	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)	Material type
1	64	54	52	15	Quartzite
2	63	105	40	15	Silcrete
3	45	43	56	19	Mudstone
4	57	—	—	—	Mudstone
5	144	—	—	—	Mudstone
6	140	—	—	—	Quartzite
7	113	—	—	—	Flint
8	180	—	—	—	Mudstone
9	82	78	53	19	Chert
10	44	45	57	22	Chert
11	82	75	58	17	Flint
12	115	71	47	10	Chert
13	22	77	48	26	Chert
14	34	78	62	16	Mudstone
15	38	37	38	9	Chert
16	34	—	—	—	Chert
17	38	53	45	14	Chert
18	99	73	65	15	Silcrete
19	64	55	64	20	Mudstone
20	96	147	47	10	Quartzite
21	40	51	47	17	Chert
22	32	58	39	13	Chert
23	56	65	49	20	Flint
24	290	62	112	37	Obsidian
25	154	53	94	22	Obsidian
26	69	63	54	17	Obsidian
27	42	56	52	11	Obsidian
28	35	52	41	12	Obsidian
29	31	47	52	10	Obsidian
30	51	69	53	10	Obsidian

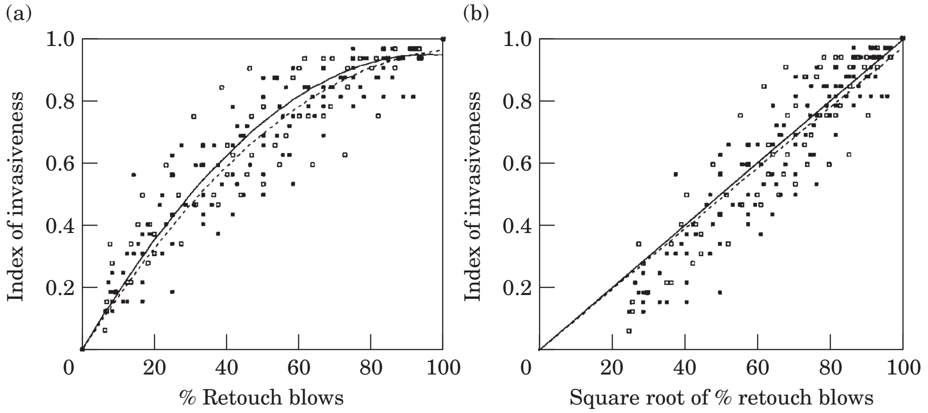

Figure 5. Scatter plot of the relationship between percentage of total retouch blows to each flake and the index of invasiveness for high and low quality raw materials; (a) index plotted against percentage retouch for high ($r^2=0{\cdot}984$) and low quality materials ($r^2=0{\cdot}981$), (b) index plotted against square root of percentage retouch for high ($r^2=0{\cdot}983$) and low quality materials ($r^2=0{\cdot}982$). ■ = High quality raw materials (solid line); □ = Low quality raw materials (dashed line).

the right of the line of best fit. Conversely, rotation can also cause results to fall to the left of the line in instances where a fresh face is retouched, such that new segments rapidly increase in value. The variation resulting from rotation should increase for a time simply because bifacially flaked artefacts must be rotated at some point, and because the probability of this taking place increases as the sequence progresses. Variation decreases again toward the end of the sequence as flake scars become so invasive that demotions occur with decreasing frequency and unretouched surfaces no longer exist. Naturally, rotation will

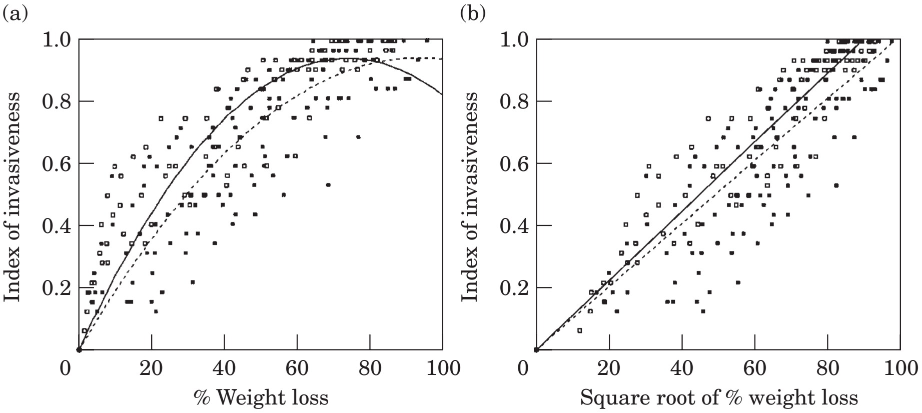

Figure 6. Scatter plot of index of invasiveness against percentage weight lost from each specimen; (a) index against % weight lost for high quality ($r^2=0\cdot963$) and low quality ($r^2=0\cdot968$) materials, (b) index against square root of % weight lost for high quality ($r^2=0\cdot963$) and low quality ($r^2=0\cdot981$) materials. ■ = High quality raw materials; □ = Low quality raw materials.

not affect the rate of index increase for unifacially retouched artefacts.

A second test of the technique is to examine the relationship between increasing index values and flake weight. Flake weight must decrease as reduction increases and should therefore decrease as the index increases. Figure 6(a) plots the relationship between the index of invasiveness and the percentage of original weight lost for each specimen over its sequence of reduction. A curvilinear relationship is again evident in the percentage of weight lost through retouching. The x axis is once again transformed (square root % weight loss) in Figure 6(b), producing a strong ($r^2=0\cdot968$, $y=79x+10\cdot1$) and significant ($F=1247\cdot5$, $P=<0\cdot0005$) linear correlation between increasing index and the proportion of weight removed. Unlike results for percentage of retouching, however, high and low quality raw materials separate slightly for percentages of weight lost. These results suggest that higher quality materials in general not only lose weight more rapidly, but also exhibit greater variability in weight loss. This might be explained in terms of the greater ease with which flakes are detached from higher quality raw materials creating greater variation in the weight range of flakes produced.

In summary, it is clear that the performance of the index when measured against percentages of retouching and weight lost is more than adequate for assessing the relative retouching of bifacially flaked artefacts. The index is also demonstrated to be relatively robust in so far as it is not overly sensitive to variation in the size, shape and raw material of flakes employed in the experiment. While the regression equations could be used to predict the original weight of artefacts, or the amount of retouching employed in manufacture, variation is of sufficient magnitude to suggest that the index better serves as a relative measure of reduction. Experimental results suggest, however, that greater precision may be obtained in estimating weight loss by modeling each raw material in an assemblage separately.

Inter-Observer Reliability

Because some difficulties may exist for accurately "eyeballing" the limits of the inner and outer zones for each of the 16 segments, this section investigates the level of inter-observer reliability obtainable with the index. In order to quantify observer error, a simple blind test was undertaken involving multiple observers, each recording the index for the same set of 10 artefacts. Ten people with a range of experience in stone artefact analysis participated in the experiment. The artefacts used in the experiment ranged from '0' to '1' on the index and were made from a variety of raw materials. To establish an accurate and independent set of index values for comparison with observer results, the index was also recorded for each specimen by actual measurement of the segment divisions and segment scores.

The results of the blind test indicate that for the population of 100 observer recordings, the mean difference between estimated index and measured index was 0·106, or 10·6%. This demonstrates a fairly low inter-observer error, and a close approximation between estimations of invasiveness and that obtained by actual measurement of segment divisions and segment scores. Not surprisingly, the mean for experienced analysts ($N=6$) was significantly lower than the overall mean at 8·1%. For experienced users of the index (i.e. more than 250 artefacts), observer error was very low at only 5·3% ($N=3$).

From these results it can be expected that with greater familiarity and training, inter-observer error should reach very low levels indeed (less than 5%?). It would also appear that the degree of observer-error inherent in the use of this index is unlikely to be greater (and perhaps much less) than that for any other measurement procedure (e.g. Fish, 1978), although this is difficult to quantify given the paucity of literature dealing with inter-observer error.

The experiments presented in this paper so far support the notion that the index of invasiveness is a reliable measure of increasing flake retouch that is suitable for a wide range of artefact types while remaining relatively unaffected by inter-observer error. Naturally, the index of invasiveness is not without some limitations, and these are discussed in the following section.

Limitations and Potential Sources of Error

While the index is designed for use in a wide range of situations, a number of limitations do exist. Perhaps the greatest limitation is that there is no reliable way to determine the amount of additional retouching a specimen has received once the index has reached its limits. For this reason, the index is of greatest value in comparing assemblages in which the majority of artefacts are not fully invasively retouched. Of course, the mere presence of less retouched artefacts in an assemblage will lower the overall mean. But in cases where much of the assemblage is fully retouched, it may be profitable to use weight or some other measure of size, as a means of ranking continuing reduction beyond the limits of the index. Results would be more accurate of course if some level of standardization existed in the original size and weight of blanks in an assemblage. Even where assemblages are dominated by fully invasively retouched flakes, it may still be worth knowing that certain transformations (e.g. pressure retouching or notching) do not occur until maximum index results have been attained.

A second limitation of the index concerns the effects that different retouching techniques, such as soft hammer and pressure, may have on the rate of increase. Depending on the skill level of knappers, thinner and more intrusive flakes may be detached using pressure and soft hammer flaking than for hard hammer percussion, potentially resulting in higher bifacial index values for less weight reduction. In this case, the difficulty of differentiating hard from soft hammer flaking could cause problems in situations where multiple techniques co-exist in the same assemblage or region. Nevertheless, different flaking techniques could be experimentally modelled and the effects taken into account. In theory, the use of such techniques should not present problems provided artefacts made using different techniques are not directly compared.

A third problem for the index stems from the error that may be introduced by steep edged retouch, such that flake scars remain marginal throughout the sequence of reduction. In such cases, the index will not readily increase beyond '0·25' (i.e. all segments = '0·5'). For this reason, the index is unsuited to measuring *reduction* on artefacts with steep-edged retouch, although it is naturally still quite capable of quantifying the *invasiveness* of that retouch (or "marginalness" as the case may be). Such steep edged retouching, however, does tend to be more characteristic of unifacially retouched flakes than bifacially retouched ones. For similar reasons, the index may also be unsuited to the measurement of retouching on artefacts that have been reduced using burin or bipolar techniques. In these cases, Kuhn's or Dibble's indices, or even Dibble and Pelcin's equation, may provide more appropriate measures of relative retouching.

Fourthly, for artefacts extensively reduced through the retouching of only a few segments (e.g. end scrapers), there will be a clear discrepancy between the index and extent of reduction as measured by either weight loss or number of retouch blows. It may be necessary either to exclude such cases from the sample or use an alternative measure of invasiveness which divides the invasiveness score by the number of retouched segments, rather than the total number of segments. This would give an index value approximating the extent of reduction far more closely than the conventional technique so far advocated in this paper.

Finally, this paper has dealt exclusively with the measurement of the index on complete artefacts. This is because artefact breakage has the potential to create error in estimations of retouch intensity, as both retouched and unretouched sections may be missing from an artefact. Consequently, measurement of the index on broken artefacts may be more complicated than for complete specimens. Developing useful measurees of retouching for broken artefacts requires further investigation in itself and will therefore be the subject of ongoing research and experimentation.

Archaeological Application: Quantifying Reduction in Northern Australia

Having demonstrated the experimental success of the index and discussed its limitations, it is important to evaluate its performance in an archaeological context. For this reason an example is provided from northern Australia which examines the operation of the index within the context of regional assemblage variability. This case study examines the rate of increase in the retouching of flakes as they are transported up to 32 km away from a chert quarry. In these assemblages, flakes are increasingly retouched into unifacial and bifacial points, adzes and scrapers as they are transported away from the raw material source. The region in which this study was carried out is located in the country of Wardaman Aboriginal people, about 330 km south of Darwin in the Northern Territory (Figure 7). The procedure used to measure the index in this example was the same as that presented above.

Measurement of the index was performed on all retouched artefacts found within six 1 km^2 quadrats positioned along Hayward Creek at increasing distance to the chert quarry source (Figure 7). A box plot of index results for each quadrat along Hayward Creek is presented in Figure 8(a). The box plot shows the spread of index results (the box and whiskers), the median for each assemblage (the central line within

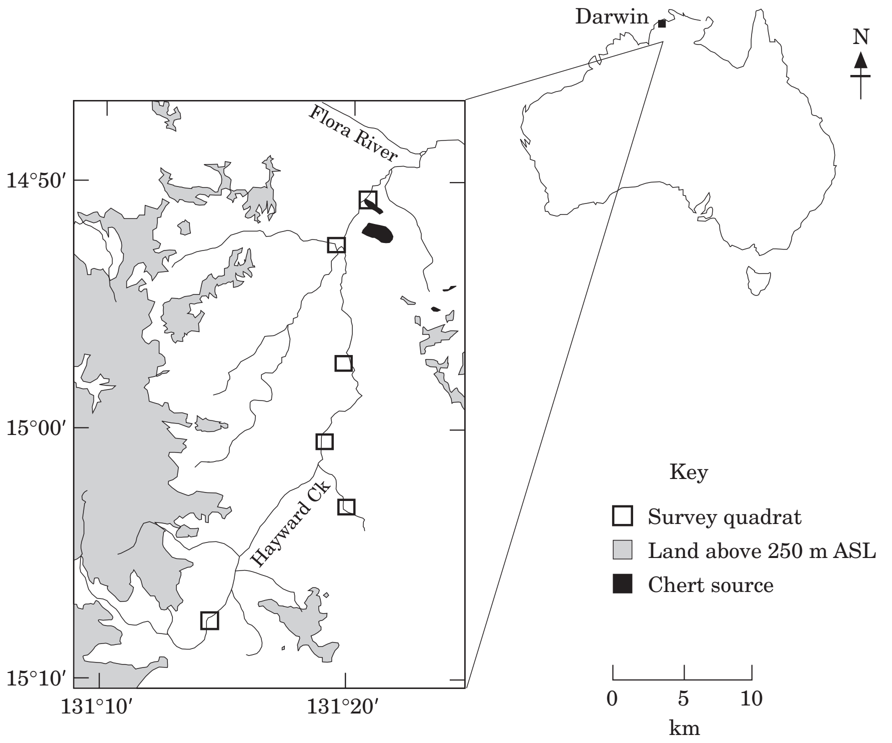

Figure 7. Map of survey area and location of six survey quadrats at increasing distance to chert source.

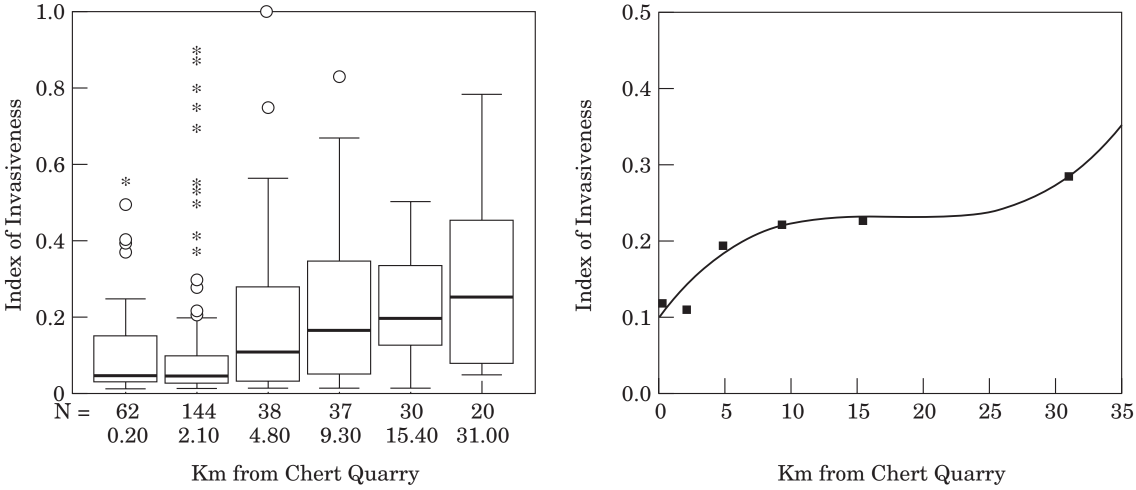

Figure 8. Plots of changing index values with increasing distance from a jasper chert quarry; (a) box plot of index values showing the spread of results; (b) mean index plotted against distance from quarry.

the solid box) as well as outliers and extremes (the circles and asterixes outside the box). It is clear from this diagram that not only does the median of the index of invasiveness increase as flakes are transported further from the chert source, but the variation in retouching also increases.

Figure 8(a) also allows use of index values to identify the presence of heavily worked implements in close proximity to the source. Following Gramly (1980, 1984), this trend could be interpreted as the increasing discard of old heavily retouched implements close to the source as raw material becomes available again and new implements are procured. In this instance, examining variation in the index is helpful in not only quantifying general trends in relative retouching, but also in identifying anomalies and outliers that may not be evident from the mean of a population alone (Figure 8(b)).

Figure 8(b) plots the increase in mean index of reduction with increasing distance from source. The mean clearly increases with distance, but does not exceed 0·3 overall. These results would seem to suggest that implements were in fact transported over far greater distances than those represented by this case study, given that artefacts with an index of '1' eventually end up back at the source.

In conclusion, this example has served merely to demonstrate that a metrical index allows graphic depiction of consistent changes in the relative retouching of stone artefacts as flakes continue to be resharpened, shaped and recycled with increasing distance from source.

Conclusion

The purpose of this paper has been to demonstrate the utility of an index that measures increasing reduction as a factor of flake scar invasiveness. Experimental testing has demonstrated the utility of the technique for the measurement of increasing retouching on bifacially retouched flakes. Experimental tests have also revealed a strong correlation between index increase and two absolute measures of reduction—the percentage of retouch blows delivered and the percentage of weight lost from a specimen. While the robusticity of this technique is also displayed, it is clear that variation in the rate of index increase is also generated by retouch rotation and raw material quality. This variation is great enough to suggest limiting the use of the index to a measure of relative reduction. While the index has several limitations, techniques are suggested that may be useful in overcoming them. The presentation of an archaeological example in this paper served to demonstrate that the index of invasiveness is not an esoteric measure of value only to those initiated into the ways of artefact analysis. Rather, it is a simple and effective measure of artefact reduction of wide-ranging utility. Because few skills are required in obtaining these measures besides basic artefact identification and area estimation, it should be useful to analysts everywhere, whether they are familiar with stone artefact analysis or not. First indications suggest that error rates for first-time users should not greatly exceed 10%, but will also fall to very low levels with continued use. Furthermore, because this technique requires no actual measurement, it may save appreciable time in the field or laboratory. As archaeologists are often interested in assessing the degree of reduction at landscape as well as site-specific scales, a powerful, but flexible and fast-paced technique is needed. The index of invasiveness should hopefully fulfill all of these requirements.

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