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What attributes are important for the measurement of assemblage reduction intensity? Results from an experimental stone artefact assemblage with relevance to the Hoabinhian of mainland Southeast Asia

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Abstract

Our understanding of variation in the technology of flaked stone artefacts from mainland Southeast Asia during the terminal Pleistocene and Holocene periods has improved little since they were originally labelled ‘‘Hoabinhian’’ in 1932. Chronological and geographical variation has been described in terms of typological differences, but there are few anthropological explanations of lithic diversity and change. An analysis of an experimentally produced Hoabinhian assemblage is undertaken here to show which flake variables are significant indicators of assemblage reduction intensity. The results show that recording the presence of overhang removal, interior platform angle, and percentage of dorsal cortex will provide robust data on the extent of assemblage reduction. A new method for detecting assemblage variation based on the location of dorsal cortex on flakes is also presented and experimentally verified. These methods are designed to take advantage of the typical geometry and reduction patterns of Hoabinhian assemblages. These findings provide another tool to build anthropological explanations of Hoabinhian archaeology.

Keywords: Hoabinhian; Lithic technology; Southeast Asia; Experimental archaeology; Assemblage reduction

1. Introduction

Cobbles are the raw materials for a variety of prehistoric technological systems, such as the Levallois of Eurasia (Brantingham and Kuhn, 2001), the limestone spheroids of North Africa and the Middle East (Sahnouni et al., 1997) and the Hoabinhian of mainland and island Southeast Asia (Moser, 2001). This paper explains the need for and proposes a system to measure the intensity of reduction using unretouched flakes from Hoabinhian flaked cobble assemblages of Southeast Asia (Fig. 1). Although the meaning and value of the term ‘‘Hoabinhian’’ has been under debate for some time (Pookajorn, 1988; Shoocongdej, 2000; Van Tan, 1994) it is used here to refer specifically to Southeast Asian lithic assemblages from the terminal Pleistocene and Holocene characterised by unifacial, centripetal and circumferential cobble reduction and resulting flakes (cf. White and Gorman, 2004).

Measuring lithic reduction intensity has become an important approach in anthropological archaeology but has yet to be applied to mainland Southeast Asian assemblages. One of the most productive recent developments in hunter-gatherer anthropology has been research exploring the relationships between technology, mobility and economic risk (Bamforth, 1991; Bamforth and Bleed, 1997; Fitzhugh, 2001; Hiscock, 1994; Kelly, 1992; Kuhn, 1995, 2004; Nelson, 1991; Parry and Kelly, 1987; Shott, 1986; Torrence, 1989). This research

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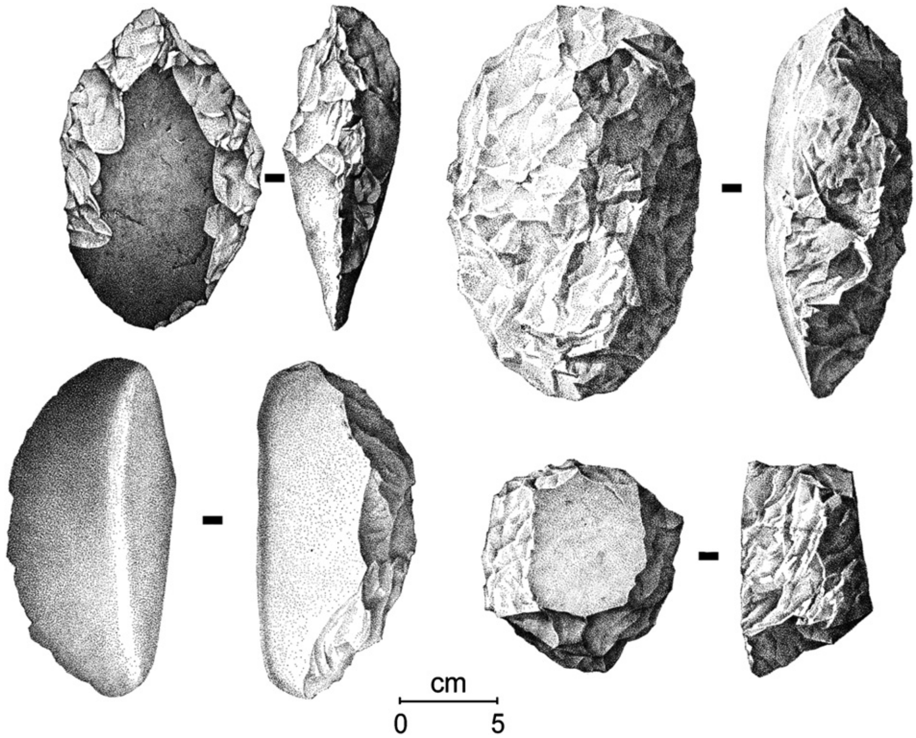

Fig. 1. Typical artefacts found in Hoabinhian assemblages. Top row: bifacially flaked cobble (L), unifacially flaked cobble (R). Bottom row: unifacially flaked ''chopper'' (L), unifacially flaked cobble (R). From van Heekeren and Knuth (1967).

usually draws on models of human behavioural ecology which predict that artefact assemblages are strongly influenced by residential mobility, resource density and quality, as well as risk and uncertainty in resource availability (Winterhalder and Smith, 2000). For the analysis of lithic assemblages, the most powerful and robust tests of these models have come from quantifying variation in the extent of artefact reduction (Clarkson, 2002; Dibble, 1995; Hiscock and Attenbrow, 2003; Mackay, 2005; McPherron, 1999).

After briefly outlining the importance of developing a systematic and robust method for Hoabinhian lithic analysis, previous contributions towards understanding Hoabinhian technology will be examined and then the results of an experiment that attempts to identify the most important attributes for measuring Hoabinhian assemblage reduction will be presented. Finally, the advantages and limitations of applying this approach to archaeological assemblages are discussed.

2. Quantifying lithic reduction

Numerous studies have documented general measures of core reduction in assemblages showing that core reduction exerts considerable influence upon various attributes of lithic assemblages (Dibble et al., 1995). Analysis of Eurasian assemblages show that as core reduction increases, the number of blanks per core and extent of core preparation also increase (Bar-Yosef, 1991; Marks, 1988; Montet-White, 1991). Similarly, as core reduction increases in Eurasian assemblages, average core size, flake size, flake platform area, and cortex decrease (Henry, 1989; Marks et al., 1991; Newcomer, 1971). Studies of Hoabinhian assemblages make limited use of these general indicators of core reduction intensity (Reynolds, 1989, 1992; Shoocongdej, 2000; White and Gorman, 2004). These indicators are used only as assemblage descriptors while the overall assemblage interpretation is still based on typological analyses (Shoocongdej, 1996a,b). The limited use of these core reduction indicators in Hoabinhian assemblages may be because there has been little experimental work to demonstrate their relevance.

In addition to measuring core reduction, a variety of methods have been developed for quantifying flake reduction for assemblages around the world (Clarkson, 2002; Dibble, 1987; Kuhn, 1990). These methods are based on flake cross-section geometry, flake retouch perimeter, flake retouch height, flake retouch invasiveness, flake allometry and typological comparisons. These methods have been examined in detail by Hiscock and Clarkson and they conclude that the flake retouch height and invasiveness measurements are the most effective metrics (Clarkson, 2002; Hiscock and Clarkson, 2005a,b). Unfortunately most of these methods are poorly suited for analysing Hoabinhian assemblages because these assemblages typically have very low proportions of retouched flakes and few or no artefact forms with clear morphology and size discontinuities (Matthews, 1964; Reynolds, 1989, 1992; Shoocongdej, 1996a,b; White and Gorman, 2004). A customised and standardised method for measuring reduction in Hoabinhian assemblages would provide the necessary data for comparing relative reduction intensity within and between assemblages from different contexts.

Methods for systematic comparison and analysis of Hoabinhian assemblages are important in the pursuit of answers for a number of important problems. First, although the Hoabinhian has been securely identified in Vietnam, Thailand, Laos, Cambodia, Malaysia and parts of Indonesia, some authors have argued for an extremely wide geographic and chronological distribution for the Hoabinhian (Bowdler, 1994; Matthews, 1966; Moser, 2001). However, there has been little work towards developing methods to understand assemblage variation at large scales and evaluate these claims. Previous statements about the geographical and chronological variation of the Hoabinhian rely on changing proportions of tool types and general statements about artefact size (Anderson, 1990; Bulbeck, 2003; Matthews, 1964). These typological comparisons provide limited insights into differences in mobility, land-use, economy, and technological organisation (Anderson, 1990; Bulbeck, 2003).

Second, Hoabinhian lithic assemblages are important evidence in the debate about whether a foraging mode of subsistence was possible in tropical forests before historical times (Bailey and Hedland, 1991; Bulbeck, 2003). A better understanding of the range of variation of Hoabinhian assemblages will show how people adapted to tropic forest foraging conditions. Shoocongdej's analysis of material excavated from Lang Kamnan rockshelter at Kanchanaburi, western central Thailand (Shoocongdej, 2000) is one of the few substantial anthropological studies of tropical forest adaptations by Hoabinhian people in mainland Southeast Asia. Shoocongdej's lithic analysis (following Shott, 1986) relies on the identification of artefact utilisation in a quartzite assemblage. Studies of artefact use by Kim Dzung (1994), Kamminga (1982) and Bannanurag (1988) have found that identifying traces of artefact use on quartzite is problematic because its brittle granular edges tend to fracture subconchoidally without preserving distinctive traces of usewear, making it difficult to identify the causes of fractures. These mechanical properties of quartzite are typical of many of the other raw materials that Hoabinhian assemblages are made from. This problem highlights the need for a method of lithic analysis that does not rely on identifying traces of use in Hoabinhian assemblages.

Third, Hoabinhian assemblages were probably an important technology during the processes of domestication in mainland Southeast Asia and current understanding of the relationship between Holocene technological and subsistence changes is very limited (Glover, 1977; Yen, 1977). Reynolds' analysis of material excavated from Banyan Valley Cave, northwest Thailand (Reynolds, 1992), is typical in its description of Hoabinhian lithics that are stratigraphically associated with cord-marked ceramics, a polished adze and a flaked adze that appears to be a polished adze preform. Similarly, Treerayapiwat (2005) has described Hoabinhian lithics stratigraphically associated with cord-marked ceramics and iron artefacts at Ban Rai rockshelter, northwest Thailand. Despite these important descriptions, no analysis has yet addressed how Hoabinhian flaked stone technology relates to the appearance of polished stone artefacts, ceramics and metal in the middle and late Holocene, nor have they addressed whether flaked and polished stone technologies are historically related or if the polished technology is an intrusive tradition (Bellwood, 1993).

Finally, a robust method for measuring reduction intensity in Hoabinhian assembles will permit investigation of assemblage variability relating to changing ecological variables. Metcalfe and Barlow (1992) show that the amount of effort invested in lithic technology can be modelled using central place models developed by behavioural ecologists. A simple version of this model predicts that foragers will optimise technological provisioning by increasing lithic reduction intensity in proportion to the time required for transport and procurement of raw material (i.e. distance to the sources). This means that measurements of assemblage reduction intensity can be used as indicators of adaptive strategies under conditions of fluctuating transport costs (Beck et al., 2002). In the case of the Hoabinhian, this approach has potential to provide detailed insights into the flexibility of behaviours when comparing assemblages from different geographical contexts and provide an understanding of technological responses to climate changes throughout prehistory in mainland Southeast Asia.

3. Previous contributions towards understanding Hoabinhian technology

The method proposed here builds on three previously published studies of Hoabinhian lithic reduction. First, White and Gorman (2004) analysed variation in technological variables of flakes from Tham Phaa Can in northwest Thailand. Their study demonstrated that two sequences of flake production could be discerned in the assemblage, and that the conventional assumption of the Hoabinhian as an amorphous technology requires rethinking. White and Gorman's study is significant because it is the first to consider the analytical potential of Hoabinhian flake technologies rather than core and tool typologies. A second technological study is the analysis by Reynolds (1989) of a small assemblage of lithics ($n = 385$) from Tham Khao Khi Chan rockshelter in southern Thailand, where he produces a typology based on technological attributes of flakes and cores. He makes some brief observations about the ratio of cores to flakes and flake dorsal cortex types (primary, secondary and tertiary) as indicators of reduction intensity. The main limitation of these two studies is that they do not supply an interpretative framework, such as the behavioural ecological model noted above, to link the descriptions of flake technology to an explanation of human behaviours.

In his comparison of core and flake attributes from two cave assemblages from northern Vietnam, Nishimura (2005) similarly focuses on the technological attributes of flakes. He arbitrarily defines a series of flake attributes as indicators of expedient or curated assemblages and interprets assemblage variation as a direct reflection of frequency of site use. The more expedient assemblage (Bung rockshelter) is interpreted as a temporary camp and the more curated assemblage (Xom Trai) as a base camp that was more frequently visited. Nishimura suggests that the intensity of site use may be explained by the environmental context of the sites, since he considers Xom Trai to be in an ecologically richer location than

Bung rockshelter. This interpretation associating expedient technology with low frequency of site occupation is difficult to reconcile with ethnographic and ethnoarchaeological work indicating that expedient artefacts are usually associated with longer durations of site occupation (Kelly, 1995; Parry and Kelly, 1987) and the provisioning of places rather than of mobile individuals (Kuhn, 1995).

4. An experimental approach to quantifying Hoabinhian reduction

These descriptions of previous studies suggest that there is still a pressing need for robust measures of Hoabinhian assemblage reduction. Shoocongdej (1996) has noted that the lack of systematic lithic production experiments using river cobble material in Southeast Asia makes it difficult to measure assemblage reduction with confidence. In an attempt to help assuage this problem, the experiment described here was designed, following Amick et al. (1989), with two objectives in mind: first, to observe how a large number of flake variables change over the course of core reduction; and second, to identify the most responsive variables for use in archaeological analysis.

A simple experiment was designed to record changes in 28 metric and technological variables of flakes struck by the author from 30 river cobbles by hard-hammer percussion. Cobbles of a variety of different sizes and shapes were collected from the Lang River, adjacent to the Tham Lod rockshelter archaeological site in northwest Thailand (Shoocongdej, 2004). The raw materials of the cobbles were orthoquartzite ($n = 25$), sandstone ($n = 3$) and andesite ($n = 2$). These raw materials have similar mechanical properties and were not separated for analysis. Detached pieces over 5 mm with unambiguous positive scars (having evidence of a bulb of percussion or bending initiation) were recorded as flakes. The order of each flake was recorded as they were struck and flaking continued until flakes could no longer be detached using freehand percussion. Although the cores are not discussed here, core mass was recorded after each flake detachment and the final state of the core was also recorded.

The experimental cobble reduction was carried out in order to create a variety of typical Hoabinhian typological forms (cf. Colani, 1927; Forestier et al., 2005), simulating a range of possible reduction sequences, until the cobble could no longer be held for flaking. Although it is difficult to generalise about typical Hoabinhian assemblages because the number of well-described assemblages is small and many pieces are unretouched and amorphous (especially flakes), they have historically been characterised by the presence of sumatraliths (ovoid cobbles flaked unifacially and invasively around the entire circumference), short axes (sumatraliths broken along the short axis of the cobble) choppers (ovoid cobbles flaked unifacially and invasively along half of its circumference following the long axis of the cobble) and other variations of unifacially flaked cobbles (Fig. 1). Bifaces are rare in Hoabinhian assemblages from mainland Southeast Asia and small numbers have been described from the Malay Peninsula (Bulbeck, 2003). To date there is no convincing evidence of systematic reworking of retouched tools and the preparation of core forms for standardised products in Hoabinhian assemblages. This experiment was undertaken at the same time and place as the author's collection of data from the Hoabinhian assemblage at Tham Lod, so the experimental flaking was modelled on the range of Hoabinhian cores and flakes found in this archaeological assemblage as well as those described in publications of other sites (e.g. Forestier, 2000; van Heekeren and Knuth, 1967). Moser (2001) observes that Hoabinhian flakes are produced by hard hammer percussion, so cobbles were used here as hammerstones. After a core was completely reduced, every flake was given an individual percentile ranking reflecting its position in the sequence of all flakes removed from that core. To analyse the data, flakes from all 30 cores were ordered together by their individual percentile ranking and then arbitrarily divided into ten classes to form a continuum of reduction intensity from early reduction (1) to late reduction (10). This means that all cores and therefore a variety of reduction sequences contributed flakes to each of the ten classes of the reduction intensity continuum.

5. Results

The 30 cobbles produced a total of 625 flakes and 159 non-flake pieces. The average number of flakes per cobble is 21 with a maximum of 72 and most cobbles producing less than 30 flakes (Figs. 2 and 3). The patterns of variation in the measured variables are complex, as indicated by the results of a principal components analysis that shows a high number of components (12) are necessary to explain 80% of variance. As a first step to understanding how flake morphology and

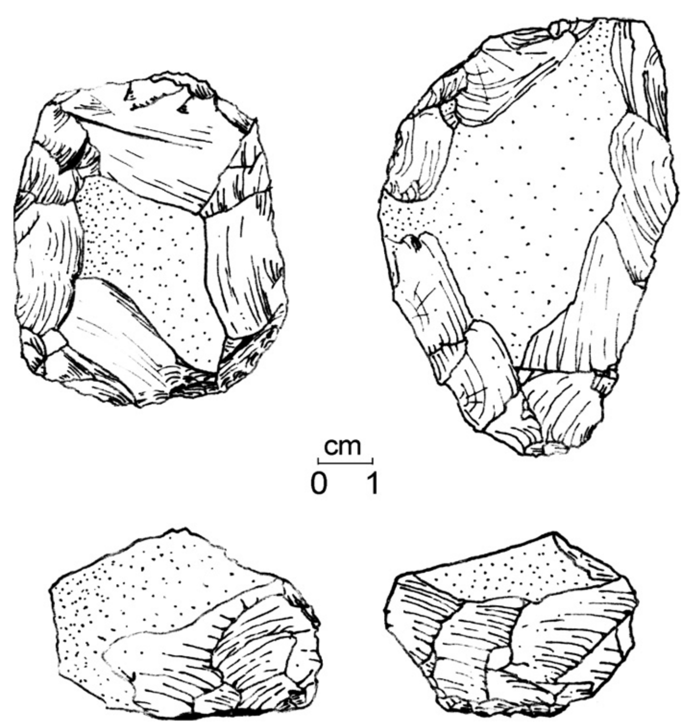

Fig. 2. Artefacts from the experimental assemblage. Top row: two unifacially flaked cores. Bottom row: view of dorsal surfaces of two flakes.

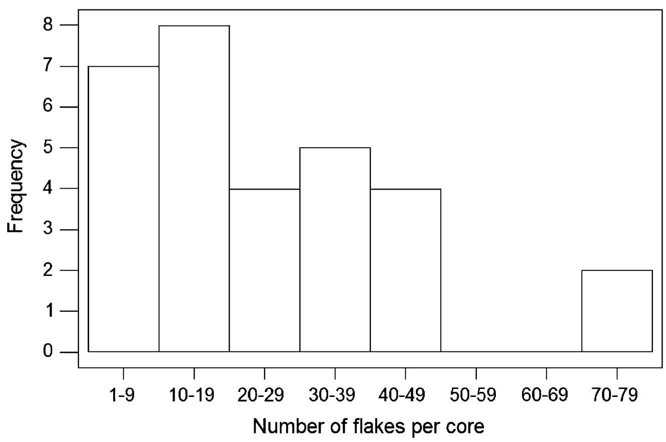

Fig. 3. Frequency distribution of flakes per core in the experimental assemblage.

attributes vary through the reduction sequence, a series of basic attributes are examined here. A simple model of reduction intensity of flaked cobble assemblages can be employed to generate predictions about which variables are most likely to reflect reduction. The geometry of the ovoid cobbles typical of Hoabinhian assemblages suggests that variables relating to dorsal cortex and dorsal flake scars are likely to have simple linear or curvilinear relationships with reduction intensity. Interior platform angle and overhang removal are also likely to be related to reduction because they are sensitive to the size and inertia of the core. Flake mass is unlikely to correlate with reduction intensity because the oblate spheroid geometry of the cobbles will probably result in short early reduction flakes made by acute, glancing blows on the perimeter of the cobble, followed by mid-reduction flakes that are as long as the maximum thickness of the cobble and finally followed by late-reduction flakes that are small because most of the mass of the cobble has been already removed. The following analyses test these predictions of this simple model.

5.1. Mass

Flake mass is used as a general measure of flake size and has been observed as reliable indicator of reduction for biface manufacture (Amick et al., 1988; Magne and Pokotylo, 1981). For this experiment, flake mass does not significantly vary according to the extent of reduction ($r = 0.017$ $p = 0.663$, Kruskal–Wallis $\chi^2 = 5.691$, $df = 9$, $p = 0.770$) and is not a useful reduction indicator. Mauldin and Amick (1989) also observed that size variables were poor indicators of reduction and suggested it was probably because of the small flakes that are continuously produced throughout the reduction process. In this case the oblate spheroid model appears to be a good explanation of the distribution of flake lengths.

5.2. Overhang removal

Overhang removal (OHR), also known as platform trimming or platform preparation, is defined here as the presence of a series of overlapping small (an arbitrary scar length of <15 mm is used here) step-terminated flake scars initiated from the platform surface onto the dorsal surface of a flake (Clarkson and O'Connor, 2005). These scars are often interpreted as the removal of a lip left on the platform by earlier flake removal and are presumably generated to maintain a certain core morphology for the predictable removal of flakes as core size decreases and platform angles increase (Clarkson and O'Connor, 2005). In this case however OHR was also noted to occur as a result of accidental platform edge shattering as well as platform maintenance, suggesting that it results from both intentional and unintentional behaviours. As predicted, this experiment shows a strong and significant positive correlation between the presence of OHR and increasing intensity of cobble reduction ($r = 0.892$, $p = 0.001$, Fig. 4).

5.3. Interior platform angle

As suggested by the model, the increase in the percentage of flakes with OHR is probably a result of shifting core geometry and size as flake removal progresses. Interior platform angle (IPA) was measured on flakes as the angle between the striking platform and the ventral surface with a goniometer. Despite a number of studies of platform angles showing that it is difficult to measure reliably (Dibble and Bernard, 1980), in this experiment there is a significant correlation between IPA and extent of reduction ($r = 0.307$, $p < 0.05$). The IPAs of the early reduction flakes are typically less than 90° and then in the later stages of reduction the values cluster around 90–100° (Fig. 5). The 90–100° values are probably asymptotic because it is difficult to remove flakes at higher angles without risking aberrant hinge and step terminations that alter the morphology of the core's free face and reduce its useful life (Macgregor, 2005; Whittaker, 1994). An interesting result of this experiment is that the increasing percentage of OHR and the increasing IPA appear to be directly linked. Increases in flake IPA result in more acute platform angles on the core, creating lips on the platform that are removed

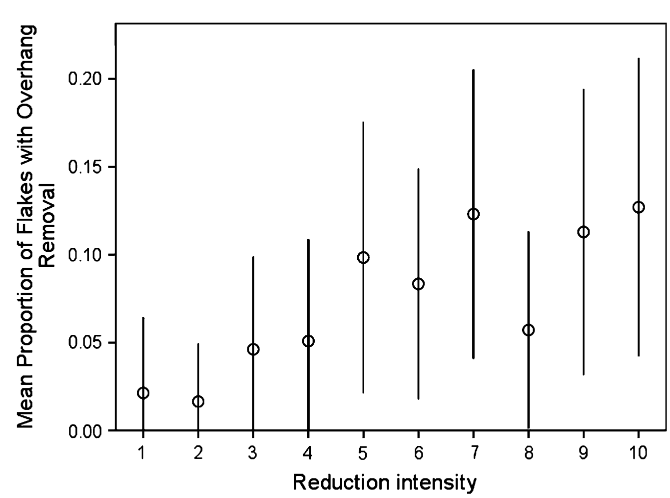

Fig. 4. Plot of changes in the mean proportion of flakes with overhang removal and increasing reduction. Error bars show 95% confidence interval of mean.

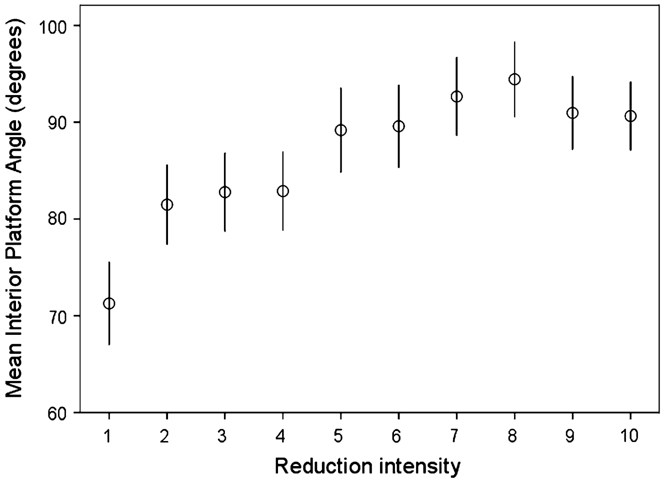

Fig. 5. Plot of changes in mean flake interior platform angle with increasing reduction. Error bars show 95% confidence interval of mean.

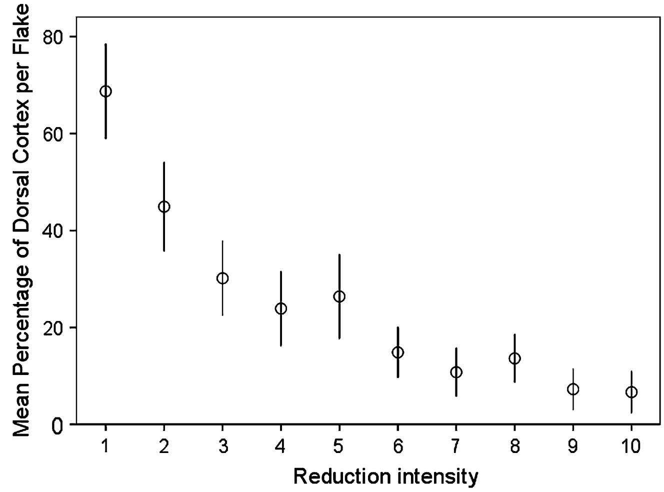

Fig. 6. Plot of changes in mean percentage of flake dorsal cortex with increasing reduction. Error bars show 95% confidence interval of mean.

when the core is prepared for another flake removal, leaving traces of OHR.

5.4. Percentage of dorsal cortex

The amount of cortex (the skin on the outer surface of the cobble formed with chemical or mechanical weathering) on the dorsal surface of a flake is another important indicator of an assemblage's extent of reduction (Cowan, 1999; Morrow, 1984; Odell, 1989). The popularity of this variable is based on the simple assumption that flakes with a high percentage of cortex come from the outer surface of the core and once that outer surface has been completely removed, all subsequent flakes will be noncortical. Thus, the model predicts that more extensive the core reduction, the higher the proportion of noncortical flakes in an assemblage (cf. Dibble et al., 2005). In this experiment the percentage of flake dorsal cortex (measured in intervals of 10% for each flake) is significantly correlated with the extent of cobble reduction ($r = -0.491$, $p < 0.05$). The mean percentage of dorsal cortex for the experimental assemblage is 25% and the standard deviation is 32%. Although there is a good statistical correlation for the overall reduction sequence, Fig. 6 shows that dorsal cortex is most sensitive to variation in the early stages of core reduction. In the later half of the reduction process the average percentage of dorsal cortex is low but the small variation between the later stages suggests the influence of some stochastic effects. These results support the predictions of the model and corroborate those of earlier studies suggesting that cortex percentage is most useful as an indicator of early reduction (Dibble et al., 1995, 2005; Magne and Pokotylo, 1981; Mauldin and Amick, 1989).

5.5. Dorsal flake scars

Closely related to the percentage of dorsal cortex is the number of flake scars on the dorsal surface of flakes. In this experiment the number of flake scars per flake ranged from 0 to 8 with a mean of 1.72. The number of dorsal flake scars per flake is significantly correlated with reduction intensity ($r = 0.308$, $p < 0.0001$, Fig. 7). However, Mauldin and Amick (1989) note that dorsal flake scars can also be highly correlated with flake size and in this case the correlation with flake mass is stronger ($r = 0.424$, $p < 0.0001$) than the correlation with reduction intensity. On the other hand, there are weak but significant correlations between standardised numbers of flake scars per flake and reduction intensity (standardised by dividing by mass or by flake surface area; mass: $r = 0.193$, $p < 0.0001$; flake surface area: $r = 0.293$, $p < 0.0001$). Fig. 7 suggests that this variable becomes asymptotic as reduction increases, probably because the constant size of flakes limits the maximum number of visible flake scars to about two. These results provide only equivocal support for the model's predictions, suggesting that the number of dorsal flake scars may be a less reliable indicator of reduction intensity than the other variables discussed here.

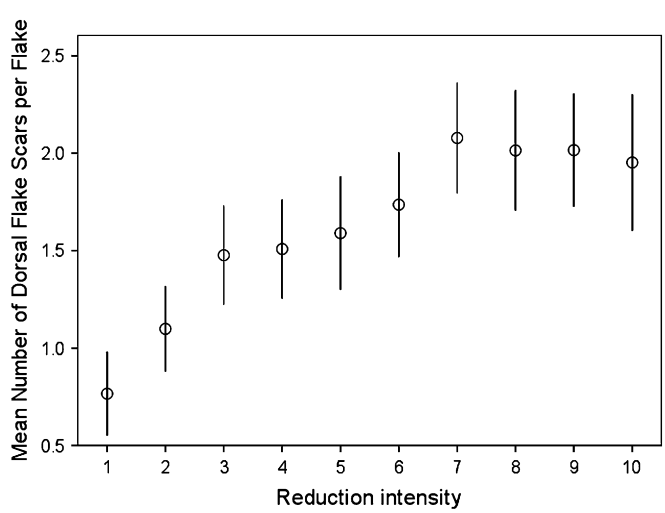

Fig. 7. Plot of changes in the mean number of flake scars on the dorsal surface on flakes with increasing reduction. Error bars show 95% confidence interval of mean.

5.6. Dorsal cortex location

Nishimura (2005) has suggested that the location of dorsal cortex in flakes in Hoabinhian assemblages in northern Vietnam may indicate stages of tool making. He noted that early stages are characterised by flakes with 100% dorsal cortex (primary flakes) and flakes with a crescent-shaped distribution of dorsal cortex (cortex extending from the platform, around one margin and contacting the distal end). He notes that the later stages of ''resharpening or otherwise rejuvenating an edge [on a core tool]'' results in flakes with cortex on the distal end of the flake and flakes without any dorsal cortex (tertiary flakes) (cf. Jeremie and Vacher, 1992; Nishimura, 2005). This cobble reduction experiment demonstrates that Nishimura's four classes (Fig. 8) are an exhaustive classification because they describe more than 98% of flakes (Fig. 9).

Cortex location has been used to distinguish between multidirectional core reduction, bifacial reduction and dart production (Tomka, 1989) but does not appear to have been systematically investigated as an indicator of reduction intensity. This experiment shows that numbers of flakes with 100% cortex and crescent patterned cortex significantly decrease as reduction continues while numbers of flakes with distal cortex and no cortex increase significantly (Table 1). Table 1 also shows that the four classes are relatively insensitive to flake size, making them more reliable indicators of reduction than counts of dorsal flake scars. Fig. 10 shows how the majority of flakes change from primary to tertiary very early in the reduction process, supporting the earlier observation that major changes in dorsal cortex occur during the early stages of reduction. The important detail in this figure is that it shows the middle stages of reduction can be identified in the region with <10% crescent-pattern flakes and >20% distal-patterned flakes. The usefulness of these two flake classes as indicators of mid-reduction is also indicated by their good correspondence with two other reliable indicators of reduction intensity, dorsal cortex percentage (Fig. 11) and IPA (Fig. 12).

The reason that these flake classes are good indicators of reduction is probably because unifacial cobble reduction typically begins with removal of primary and crescent-patterned flakes as flakes are removed from the circumference of the cobble, followed by the appearance of distal-patterned flakes as flake removal begins to overlap previous scars around the circumference of the cobble and invade towards the centre of the cobble. Distal-patterned and tertiary flakes become more abundant when flake removal is increasingly invasive and core rotation increases so that flake scars intersect with previous scars.

Although this four class system has yet to be used to interpret any archaeological assemblages, it can be shown to have some advantages over other methods of recording dorsal cortex. Firstly, the four-class system has stronger correlations with reduction intensity and weaker correlations with flake size than the popular primary–secondary–tertiary system (secondary flakes and reduction intensity: $r = -0.232$, $p < 0.001$; secondary flakes and flake mass: $r = 0.265$, $p < 0.001$).

Secondly, Sullivan and Rozen (1985) note that the primary–secondary–tertiary system is problematic because of false assumptions and inconsistent definitions across different analysts. To assess the level of inter-observer reliability available with the four flake classes a series of simple blind tests were undertaken. Ten people with a range of experience in lithic analysis classified thirty flakes into the four cortex classes plus an ''other'' category. Their results were compared to the author's and the average difference was 10.6%. Two of the more experienced participants had no errors in their classification, suggesting that with more training and familiarity, error levels can be very low or zero. These results mean that inter-observer errors in the use of these four classes are relatively low (cf. Clarkson, 2002) and unlikely to be greater than other measurements (Fish, 1978).

Finally, the distal cortex class provides valuable resolution for the later stages of the reduction process. Although flakes

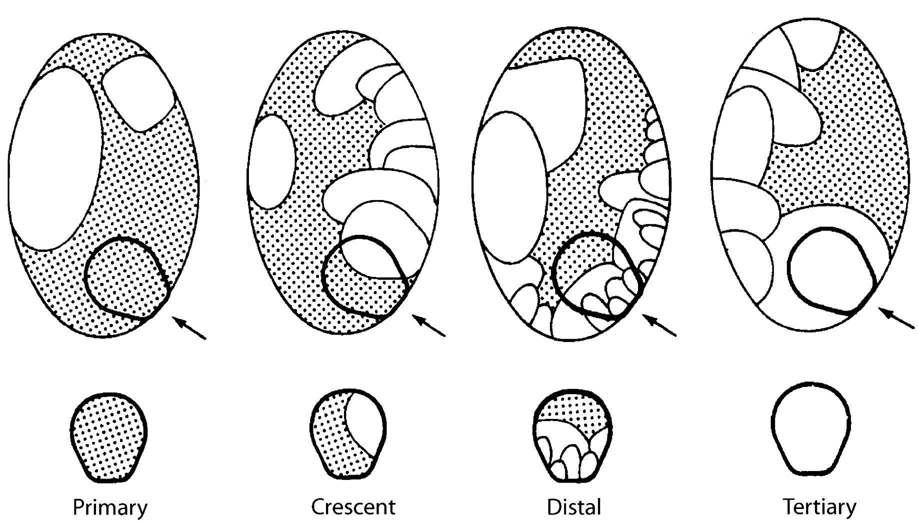

Fig. 8. Four classes of dorsal cortex location identified by Nishimura (2005). Modified from Jeremie and Vacher (1992).

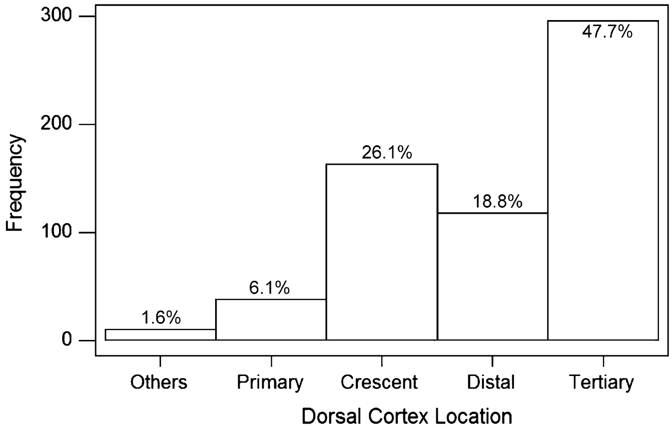

Fig. 9. Frequency distribution of the four classes of dorsal cortex location.

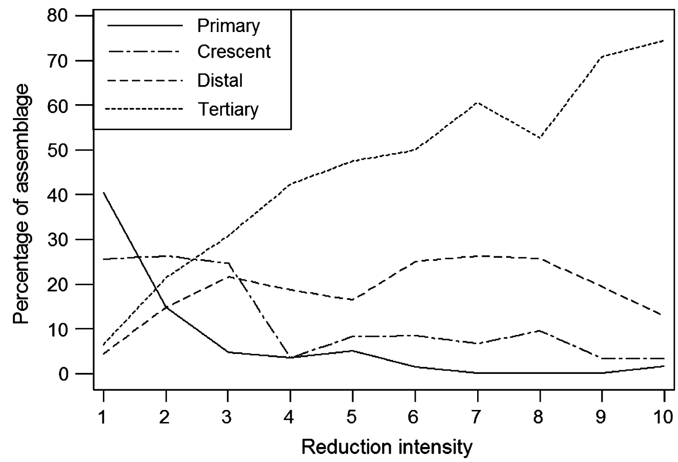

Fig. 10. Changes in the proportions of the four classes of dorsal cortex distribution with increasing reduction.

with distal cortex have a low correlation with overall reduction (Table 1), they are useful markers of intensive reduction because they are most abundant in the second half of the reduction process, compared to tertiary flakes that become abundant relatively early in the reduction process. This feature of the distal cortex flakes is especially relevant in assemblages where flakes are transported out of the assemblage or partially worked cores are introduced and reduced further so that the proportions of primary and tertiary flakes no longer accurately represent the extent of reduction occurring at the site.

6. Discussion

This experiment was designed to reproduce the particular qualities of Hoabinhian assemblages, especially the unifacial circumferential, centripetal reduction of ovoid cobbles (Forestier, 2000). The results presented here support the predictions of a simple model of assemblage reduction and suggest that there are a number of simple technological attributes of flakes that are robust indicators of the intensity of reduction in Hoabinhian lithic assemblages. Analysis of the experimental data showed that the most important variables for measuring reduction intensity are the presence of overhang removal, interior platform angle and percentage of dorsal cortex. These attributes have the advantages of being well understood and widely used by lithic analysts as well as being easily recognisable, allowing rapid and accurate data collection. In addition to these familiar attributes a new method of classifying flakes according to dorsal cortex location has been proposed. This new method was shown to be similarly useful for measuring assemblage reduction intensity and its reliability is demonstrated by relatively low inter-observer error.

A further advantage of the attributes discussed here is that they can be used to produce summary ratios describing an assemblage for comparison with other assemblages. These ratios represent a continuous measurement of assemblage variation without imposing arbitrary stages or events onto the reduction process. Summary ratios of flake attributes can be used to describe the extent of cobble reduction even when cores have been removed from the assemblage. Incidentally, a surprising result of the experiments is that the number of flake scars on a core at the end of the reduction process has no significant correlation with the number of flakes removed from that core ($r = 0.251$, $p = 0.226$) (cf. Braun et al., 2005). This

Table 1
Correlations of four classes of dorsal cortex location with reduction intensity and flake mass

Class	Reduction		Mass	
	r	*p*	*r*	*p*
Primary	−0.313	<0.0001	0.015	0.700
Crescent	−0.317	<0.0001	0.056	0.159
Distal	0.059	<0.0001	0.287	<0.0001
No cortex	0.375	<0.0001	−0.271	<0.0001

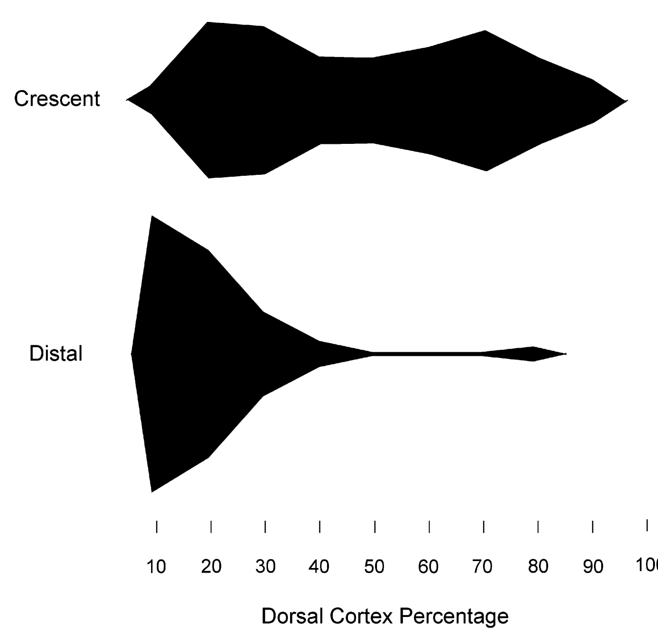

Fig. 11. The relationship of dorsal cortex location to percentage of dorsal cortex. The widths of the shapes are proportional to the percentages of those classes in the assemblage.

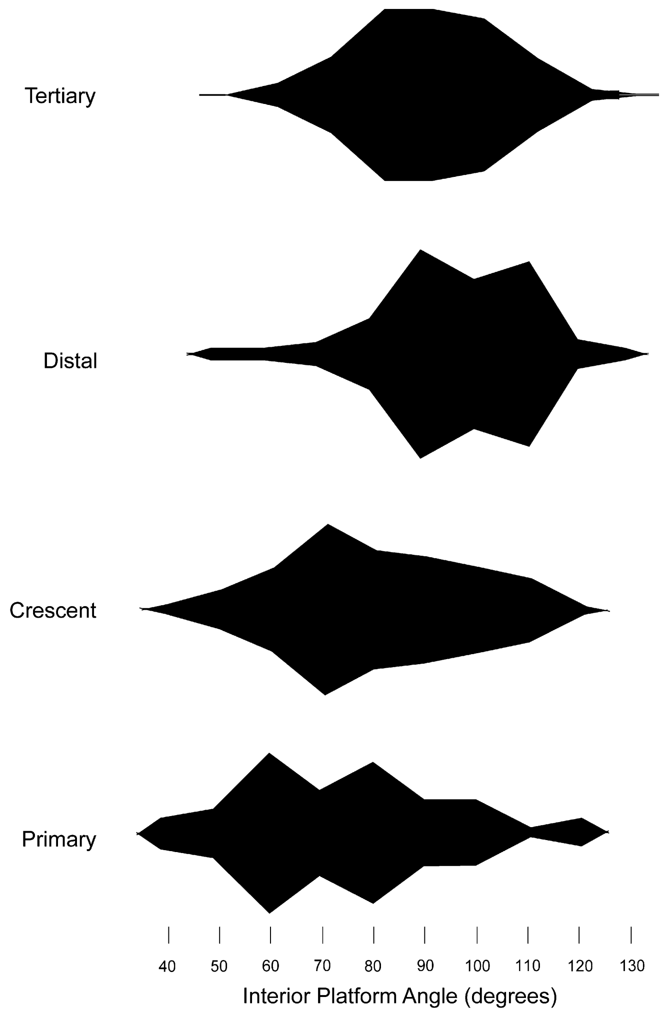

Fig. 12. The relationship of dorsal cortex location to interior platform angle. The widths of the shapes are proportional to the percentages of those classes in the assemblage.

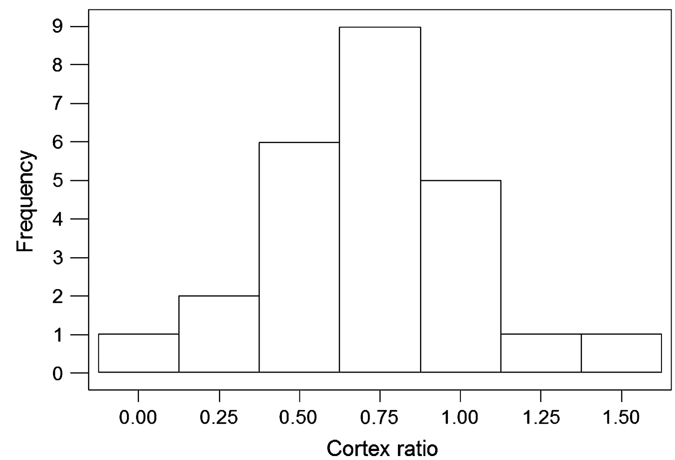

Fig. 13. Distribution of cortex ratios for the experimental assemblage.

highlights the importance of data from flakes in accurately understanding lithic reduction in Hoabinhian assemblages.

Dibble et al. (2005) have similarly considered how to identify the degree of importing or exporting pieces in an assemblage. To investigate behaviours that affect the amount of cortex in an assemblage they propose a ''cortex ratio'' (calculated as the observed total surface area of cortex in an assemblage divided by the expected surface area, derived from geometric modelling of cores) and they conduct experiments to explore how the ratio is affected by different behaviours. Although this cobble reduction experiment was not designed to test the findings of Dibble et al. (2005), the experimental data can be used to verify the index's usefulness for Hoabinhian assemblages. In this experimental assemblage a sphere model was found to be the most accurate approximation of core surface area and the resulting cortex ratios ranges from 0.29 to 1.42 with a mean of 0.87 and a highly peaked distribution (Fig. 13). This experiment shows that the observed cortex surface areas are similar to the predicted values, resulting in cortex ratios very close the ideal value of one. This means that cortex ratio is another useful method for describing and comparing Hoabinhian assemblages because it can indicate assemblages with cores that are partially reduced and then transported away (the index value is much greater than 1), or assemblages when only later phases of reduction are occurring (the index value is much less than 1).

6.1. Limitations and potential sources of error

Shott (1996) has noted that it is not easy to design experiments that depict how ancient stoneworking actually proceeded. This experiment has tried to simulate the defining characteristics of Hoabinhian assemblages, such as unifacial, centripetal and circumferential cobble reduction. However, it is likely that Southeast Asian lithic assemblages represent a range of raw material procurement and core reduction strategies (Forestier et al., 2005; White and Gorman, 2004). Until future work describes these different reduction strategies we cannot know how well this experiment approximates the range of variation in the Hoabinhian. Nevertheless, most of the variables identified here are reliable indicators of reduction in a range of technological systems, including biface manufacture, so the variation within Hoabinhian technologies is unlikely to compromise the robustness of these measures. Finally, taphonomic and recovery processes will influence assemblages in complex ways that may influence inter- and intra-site comparisons of the technological variables discussed here. This highlights the need for detailed descriptions of deposits and excavation methods to accompany the interpretation of lithic assemblages.

7. Conclusion

The purpose of this paper has been to present some features of a robust system for measuring the intensity of flaked stone artefact assemblage reduction for Hoabinhian assemblages of Southeast Asia. It can be difficult to know what variables will be the most meaningful to record, especially when these assemblages often have many amorphous cores and very few retouched pieces. Analysis of the experimental assemblage has shown that recording the presence of overhang removal, interior platform angle, percentage of dorsal cortex and dorsal cortex location will provide robust data on the extent of assemblage reduction. The cortex index of Dibble et al. (2005) is another useful variable for understanding behaviours that affect Hoabinhian assemblages. By comparing these data between different sites and different periods we can investigate the relationships between technology, mobility and economic risk. More specifically, these variables allow for systematic analysis of assemblages to investigate important problems of the Hoabinhian, such as its chronology and distribution, its relationship to middle Holocene technological and subsistence changes and the responsiveness of this technology to changes in ecological and climatic conditions.

Much work on lithic assemblages from mainland Southeast Asia focuses on description without producing generalised interpretations presented in anthropological frameworks (Glover, 2001; Miksic, 1995). While making important contributions to understanding individual sites, this descriptive approach to lithics is limited in what it can say about the major questions of cultural history and cultural processes in mainland Southeast Asia (but see Shoocongdej, 2000 for an exception). This paper has outlined some basic and reliable methods to help archaeologists liven up lithic analysis in mainland Southeast Asia and give lithic assemblages the important role they deserve in contributing towards our understanding of globally significant issues of past human behaviour.

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