Quantifying the Size of Artefact Assemblages

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Stone artefacts are broken, burnt and weathered. Processes such as these may act differentially across categories, and will therefore affect interpretations of assemblage size and composition. This paper advocates a more detailed consideration of abundance estimates in artefact analyses, being guided by the understandings built up in archaeological studies of fauna, and begins the process by developing some basic units of measurement for counting flaked stone.

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The Problem

A curious twist of disciplinary focus has meant that while studies of archaeological fauna have fully absorbed the need to integrate taphonomic processes into interpretations, studies of archaeological stone artefacts have tended to ignore this issue. This contrast is particularly distinct in the quest to calculate the abundance of taxa in an original, behavioural/systemic, assemblage prior to alteration by taphonomic processes. For example, the pages of this journal abound with models for how to count animal units when the animals have been dismembered and bones broken, burnt and weathered (e.g., Casteel, 1977; Fieller & Turner, 1982; Grayson, 1981; Horton, 1984; Nichol & Wild, 1984; Ringrose, 1993). Even though it is clear that stone artefacts are also broken, burnt and weathered, differentially affecting destruction and/or identification of categories, it is hard to find discussions of procedures for estimating original stone artefact assemblage composition. Instead, analysts exploring the archaeological variability of stone artefacts often move directly to interpretations of assemblage use and stylistic content, with minimal concern for the complexities of quantifying abundance.

Of course many analysts of archaeological artefacts are well aware that taphonomic processes have acted on their collections. Pioneering experiments into heat shattering (Purdy, 1975) and trampling damage (e.g., Gifford-Gonzalez *et al.*, 1985), descriptive conventions for broken artefacts (e.g., Crabtree, 1972), and attempts to use weathering as a chronological indicator (e.g., Hiscock, 1985, 1990), all show that the existence of such processes have long been acknowledged (see Schiffer, 1987). A number of recent studies have integrated observations of edge damage on stone artefacts

with broader consideration of site formation processes (e.g., Dibble & Holdaway, 1993; Dibble *et al.*, 1997; Nielsen, 1991). Nevertheless, the rather different focus in artefact analysis, often concentrating on issues of artisan design, has meant that the implications of these taphonomic processes for estimation of abundance have not been much discussed. One notable exception is Shott's (2000) recent attempt to provide an estimate of tool numbers in North American sites by adapting ceramic estimation formulas developed by Orton (1993). Notwithstanding Shott's investigation the palaeontological and zooarchaeological literatures have explored the complexity of measuring abundance, while the literature on flaked stone artefacts is visibly lacking in proposals for standard measures or considerations of their interpretation. In particular there is a need to develop measures of artefact abundance that are designed specifically for lithic assemblages rather than being adapted from approaches developed for studying other classes of material culture. Instead of developing dedicated measurements, research into flaked stone artefacts has often produced very simply and patently inadequate responses to the methodological challenges posed by questions of assemblage variability, which so often involve statements of artefact abundance. For example, one approach is to count only whole flakes, while an even more dangerous approach is to count all artefact fragments and treat them as equal units (i.e., without weighting the counts). Both of these common approaches to counting are dangerous because they ignore the effects of processes such as differential fragmentation known to be so important in faunal assemblages and which are also significant in many artefact assemblages. The purpose of this paper is to explore abundance estimates in artefact analysis, and to begin the process by

Table 1. Summary of counting units

Index	Definition
NAS (Number of Artefactual Specimens)	Count of the recovered artefacts, whether complete or fragments.
NFS (Number of Flake Specimens)	Count of specimens identifiable as flakes, whether complete or fragments.
MNF (Minimum Number of Flakes)	Estimate of the minimum number of flakes necessary to account for the complete flakes and flake fragments in an assemblage. Obtained using the equation: $MNF = C + T + L$.
MNC (Minimum Number of Cores)	Estimate of the minimum number of cores necessary to account for the complete and fragmentary cores in an assemblage.
MNA (Minimum Number of Artefacts)	Estimate of the minimum number of flaked artefacts represented by an assemblage. Obtained by adding MNF and MNC.

developing some basic units of measurement for counting flaked stone.

Types of Quantitative Measures

A number of quantitative units will be needed to make sense of artefact assemblages (Table 1). An observational unit often seen in site reports is simply a count of the recovered artefacts, whether complete or pieces of artefacts. This unit is here termed *NAS* and represents the Number of Artefactual Specimens; the term “specimens” being preferred to “fragments”, following Lyman (1994: 101), because the former does not imply the state of completeness. *NAS* is comparable to *NISP* in faunal analyses; it requires that specimens are identified as artefacts, and it is extremely sensitive to the extent of fragmentation. It is likely that fragmentation is a major factor shaping assemblage variation, and while *NAS* adequately records the current form of the artefact assemblage it fails to measure the original size and composition of assemblages exposed to taphonomic processes such as fragmentation.

Consequently, it is useful to have an estimate of the quantity of knapping activities, along the lines of the *MNI* measure in faunal analysis, which defines the minimum number of animals required to account for the skeletal specimens. In studies of some artefacts one such measure might calculate the minimum number of flakes that would have to be struck off to account for the assemblage. This is the objective of Andrefsky’s suggested focus on counting flake platforms:

In all cases proximal ends have an intact point of applied force or striking platform. Flakes that contain the proximal end are probably the most important of the three flake conditions because they represent the minimal number of impacts in a production process. (Andrefsky, 1998: 87–88)

The notion that platforms, which contain the evidence for the initiation of the fracture, are one possible key to counting the minimum number of flakes is fundamentally sound. However the calculation of this derived unit is more complicated than Andrefsky has implied, and warrants further discussion. A necessary starting point is the patterns of fragmentation that are found on archaeological flakes.

Flake Fragmentation

Flakes fragment as a result of both cultural and non-cultural processes such as artefact manufacture, trampling, and thermal stress. Irrespective of the cause of the breakage, a standard classification of fragments can be, and often is employed (Figure 1). Since this classification records fracture initiation and termination it is an appropriate basis for minimum number estimates on flakes. A number of categories of flake fragments are defined as follows:

- *Complete* flakes are those that have the circumference of their ventral surface largely intact, thereby retaining the entire initiation of the fracture, the whole termination of the fracture, and much of both lateral margins. As this description implies, for the purpose of counting flakes, specimens are regarded as complete even if they have portions of the lateral margin missing (i.e., a flake from which marginal fragments have been removed—see below). These specimens are complete in the sense they have not generated longitudinal or transverse fragments.
- *Longitudinal* fragments, or “longitudinal cone split fragments” in Crabtree’s (1972) terminology, are those that have split the flake into left and right along the percussion axis. Each fragment retains a portion of the platform (often with a portion of the ringcrack in hertzian initiations), and usually a portion of the termination and one lateral margin. However these longitudinal fragments can subsequently be broken transversely, so that some longitudinal fragments may be represented only by a fracture initiation or a fracture termination. A further complication in identifying longitudinal fragments is the existence of fragments that have not split along the percussion axis. Such fragments, retaining a lateral margin but without a portion of the platform, are not regarded as longitudinal fragments but as marginal fragments (see below).
- *Transverse* fragments are those that contain portions of both lateral margins, but do not contain both fracture initiation and fracture termination. Three conventional categories are “proximal” (which contains the fracture initiation), “distal” (which contains the fracture termination), and “medial” (which

Figure 1. Illustration of fragment categories.

has neither initiation nor termination). Transverse fragmentation of a single flake can produce only one distal and one proximal fragment but can yield multiple medial fragments.

- *Marginal* fragments are those that contain portions of one lateral margin, but do not contain fracture initiation, fracture termination, or portions of the second lateral margin.
- *Surface* fragments are those that remove a portion of the ventral or dorsal surface without having any portion of the fracture initiation, termination or either lateral margin.

This diversity of fragment types confounds the view that a simple count of complete flakes and proximal transverse fragments is necessarily the best estimate of the number of flakes that have contributed to the

assemblage. For example, counting each longitudinal fragment would overestimate the original number of flakes, with each flake potentially contributing two longitudinal fragments. In some assemblages such longitudinal fragments are sufficiently frequent that the way they are counted may substantially affect minimum estimates. Another example is that counting proximal flakes will not provide the best estimate of the original number of flakes in situations in which distal fragments are more numerous. In some assemblages proximal fragments are recorded as more common than distal fragments, partly because proximal specimens may be more readily identified (particularly by inexperienced analysts) and partly because proximal fragments may be more robust. But it is not uncommon for other assemblages to have more distal than

proximal transverse fragments, perhaps because of mechanisms such as selective removal of proximal specimens for retouching, or perhaps merely through chance in sampling. This pattern may also be produced if proximal fragments were mistakenly classified as complete flakes with step terminations, a point that reinforces the importance of accurately identifying these breakage categories. More likely, distal fragments are numerous when platforms shatter during fracture, thereby leaving only the distal end as an identifiable fragment. Such circumstances should be incorporated in estimates of assemblage size.

In using this classification a small proportion of specimens display combination of the simple classes described above. For the purposes of the minimum number of calculations the above list of fragment classes also represents the classificatory priority. For example, for the calculations below a proximal part of a longitudinal fragment should be counted as a longitudinal fragment rather than a proximal fragment.

The MNF Index

Having identified categories of flake fragmentation it becomes possible to construct a means of estimating the Minimum Number of Flakes (MNF) required to account for the complete flakes and flake fragments in an assemblage. As revealed in the Andrefsky quote above, many archaeologists have focused on counts of flake platforms. Making an allowance for the production of two longitudinal fragments per flake, this approach would result in:

$$\text{Flake initiations} = C + P + (\text{LCS}/2) \quad (1)$$

where, C is the number of complete flakes; P is the number of proximal fragments; LCS is the number of longitudinal fragments.

While this calculation might be adequate in some situations, it makes unnecessary assumptions about the differential representation of fragment types. As a result equation (1) will systematically provide low estimates. The situation is improved by employing a procedure that involves counts of a greater range of fragment categories. The approach advocated here for MNF is as follows:

$$\text{MNF} = C + T + L \quad (2)$$

where, C is the number of complete flakes; T is the largest category of transverse fragments—excluding medial (i.e., the greater of the number of proximal fragments or distal fragments); L is the count of longitudinal fragments given by (3).

$$L = \text{CL} + \text{BL} \quad (3)$$

where, CL is the greater of left or right longitudinal fragments without Transverse breakage (i.e., with both

fracture initiation and termination); BL is the largest of the four relevant categories of transversely broken longitudinal fragments (i.e., right/proximal, left/proximal, right/distal and left/distal), excluding medial portions of longitudinal fragments.

The equation given in (2) ignores medial transverse, marginal and surface fragments, but for reasons explained below is considered to provide a more reliable estimate than (1). Like the standard MNI estimate in faunal analysis (2) accommodates different part representation, and can be considered a standard procedure for estimating the minimum number of flakes that contributes to an assemblage.

Discussion of the MNF Index

The usefulness of the NAS measure is self-evident, providing the most obvious characterization of assemblage abundance post-recovery; and the difficulty of interpreting these counts without an understanding of breakage is equally apparent. It is the ability of a minimum number estimate, such as the MNF index, to weight categories of fragments that makes it such a useful companion measure. One way of illustrating the usefulness of this particular approach to counting can be obtained by applying the MNF index to a collection in which the actual number of flakes struck is known. While this can be done through experiment it can also be accomplished by using refitted flakes, because it is possible to not only establish the number and sequence of flakes but also to unambiguously determine whether or not fragments belong to a single flake. Table 2 provides a comparison between the actual number of flakes and the MNF estimate for refitted flakes at a number of sites in north-west Queensland, Australia (data from Hiscock, 1988). This table also gives a simple count of complete and proximal specimens as recommended by Andrefsky (1998: 87–88), and the NAS count. Two significant points can be observed in these data:

- (1) The MNF calculation provides an estimate consistently quite close to the actual number of flakes. In four out of these five sites the MNF is either the same as the real number of flakes or one less, and a strong positive correlation exists between actual and MNF values ($r=0.995$). Of course the MNF index only provides a minimum estimate of flake numbers, and usually underestimates the actual abundance. Nevertheless, in these Australian examples MNF seems to produce a useable indication of flake abundance.
- (2) MNF yields an estimate far closer to the actual number of flakes than either NAS or counts of fracture initiations alone. It is no surprise that the NAS count is distinctly different to the actual number of flakes that produced this assemblage, since even in samples such as these with little breakage (60–80% of actual flakes are still

Table 2. Comparisons of counting approaches of Lawn Hill conjoin sets

Site	Specimen counts*							Total counts			
	Complete	Longitudinal			Transverse			NAS	Flake initiations = C + P + (LCS/2)	MNF	Actual
		CL		BL	Proximal	Medial	Distal				
		Left	Right								
Page Creek KF1	24	1	0	0	3	2	9	39	28	34	35
Page Creek KF2	29	2	2	0	2	0	6	41	33	37	37
Page Creek KF3	34	2	2	0	6	1	7	52	40	43	47
CCQ2 (A–J)	10	0	1	0	0	0	4	15	11	15	15
Lawn Hill 2	12	2	3	0	2	0	4	23	17	19	20

*No marginal or surface fragments recorded. They would inflate NAS but have no effect on the other measures.

complete) fragmentation rapidly increases NAS. Much more interesting is that the MNF index provides a far closer estimate of actual flake numbers than counting fracture initiations. This occurs because counting initiations often underestimates actual numbers more dramatically than does MNF, as in all of the five samples in Table 2. Since the counts of initiations do not recognize the frequency of distal fragments counting only fracture initiations is not suited to samples such as those in Table 2, where distal fragments outnumber proximal, and hence the MNF index is to be preferred.

While the MNF index yields an estimate (albeit a minimum one) of flake abundance in an assemblage which would often be useful, its interpretation is complex. The calculation does not formally incorporate counts of medial fragments, because the number of medial fragments per flake will vary, but there is one situation in which medial fragments can be, and should be, incorporated in the minimum estimate. When neither proximal nor distal fragments are present, medial fragments indicate flakes that are unrepresented by complete flakes or longitudinal fragments. Therefore in (2) it might be appropriate to count medial fragments when they are the only type of transverse fragment present. However the difficulty of having multiple medial fragments per flake must still be overcome by dividing the number of fragments by an estimate of the average number per flake (probably 2–4). While such a calculation carries risks it will be necessary only in rare circumstances, and probably only with small samples. In such instances it would probably be better to increase the sample.

The MNF index also suffers the same basic advantages and disadvantages as minimum number estimates in faunal studies. For example, MNF values will sometimes be affected by choices of aggregation. As the specimens are analytically sub-divided into smaller batches the MNF value will remain the same or increase. An example of this is provided in Table 3, which shows the MNF values for quartzite flakes in

Table 3. Effects of aggregation on $MNF_{Quartzite}$ at Platypus Rockshelter

Layer	C	T	L		MNF
A. Layers 1–4 treated as a single aggregate					
	221	37	20	=	278
B. Layers 1–4 treated as four separate aggregates					
1	113	19	12	=	144
2	79	14	5	=	98
3	20	9	3	=	32
4	9	2	2	=	13
		Σ	MNF	=	287

layers 1–4 at Platypus Rockshelter (Hiscock & Hall, 1988) calculated as a single aggregate and separately by layer. Calculating the same specimens in four rather than one batch results in a 3% increase in the calculated MNF. This occurs because in layers 1 and 3 the T value is based on proximal counts, whereas in layers 2 and 4 it is based on distal fragments counts; and because left and right longitudinal fragments were not in identical proportions. While MNF inflation of this kind will probably be proportionately small, because of the small number of fragment classes that can vary, it does exist. This means that MNF might vary not only because of differences in abundance and fragmentation, but also because of analytical choices.

Associated with the effect of aggregation, values will be altered by the level of detail provided about specimens. For example, calculating MNF without consideration of raw material might mean that a distal fragment and a proximal fragment would only contribute a single MNF count; whereas MNF separately for specimens of different raw material will produce higher values, because a distal fragment of say chert and a proximal fragment of quartzite might both count. Hence information about not only material, but also texture and colour, or information from conjoining will refine the MNF estimate. For this reason the nature of the aggregate employed should be specified, perhaps following Grayson (1984) using the subscript

Table 4. Indurated mudstone flakes from Sandy Hollow 1

	Specimen counts					Abundance estimates		
	Complete	Proximal	Medial	Distal	Longitudinal	NAS	Flake initiations (1)	MNF (2)
Layer 1	63	18	11	17	5	114	84	84
Layer 2	52	5	3	18	6	84	60	74
Combined	115	23	14	35	11	198	144	157

label such as $MNF_{\text{Quartzite}}$ or MNF_{Layer} . This process can even be seen in the contrast between the count of flake initiations (calculation 1 above) and MNF calculations (2) described above. Table 4 provides an illustration using mudstone specimens from the Sandy Hollow 1 site in New South Wales (Hiscock, 1986, 1993). In layer 2 the MNF value is higher using the second calculation because it allows the more abundant distal fragments to be counted rather than the small number of proximal fragments. It is because the MNF calculation recommended here ($MNF = C + T + L$) retains more information about fragmentation that it provides a better minimum estimate than results from using fracture initiations alone.

MNF calculations require accurate identification of both the artefactualness and fragment class of specimens. Even though by definition a MNF calculation such as this deals well with extensive fragmentation, there are limits to the robustness of this measure. For instance, in situations where many specimens have been extensively damaged it could be expected that identification rates would fall, yielding lower MNF estimates.

Inevitably there will be a predictable relationship between NAS and MNF. These counts should display a strong positive trend in any single assemblage, since they are both a reflection of the original number of flakes present. Hence MNF is not simply a reflection of NAS, or visa versa, since both are related to a third kind of count: the real abundance of flakes. While empirical investigations are as yet limited, because a standard MNF calculation has not been widely applied, it seems that at least in some sites and regions this strong positive relationship between MNF and NAS is demonstrated, and consequently in those cases MNF can be predicted from NAS counts. There is, however, no reason to think that either the slope or tightness of the relationship (i.e., size of residuals) is universal, and it can be expected to change with both aggregation and the extent of fragmentation/destruction.

Figure 2 presents an illustration of the possible relationships between NAS and MNF in assemblages of flaked stone artefacts. Since MNF must be equal to, or more likely less than NAS, assemblages must fall in the shaded areas. In practice there may be a lower limit to the distribution of data points, created because a

Figure 2. Model of the relationship between NAS and MNF in assemblages of flaked stone artefacts. Assemblages must fall in the shaded areas defined on the upper boundary by the unlikely possibility of only complete flakes ($NAS = MNF$), and on the lower boundary by the fact that a flake can only be broken into a finite number of identifiable fragments (modelled as 15 fragments per one MNF). Most assemblages will fall in the zone with darker shading, indicating a low level of fragmentation (modelled as six or less fragments per one MNF).

flake can only be broken into a finite number of identifiable fragments. More importantly most assemblages can be expected to fall in the zone with darker shading, indicating a low level of fragmentation (modelled as six or less fragments per one MNF). Figure 2 emphasizes the extreme differences in counts, between NAS and MNF, which will occur in highly fragmented assemblages, and it is particularly in those situations that an MNF index may enhance the interpretation of specimen abundance.

After controlling for aggregation effects, the difference in NAS values for a single MNF value will largely be caused by differences in fragmentation (see below for a complicating factor). Consequently, and not withstanding arguments of sample-size (see Grayson, 1984; Grayson & Cole, 1998), it is likely that the

NAS:MNF ratio will reveal information about the level of fragmentation, although simple interpretation of such a ratio may be difficult. This ratio should approximate the average number of fragments produced per flake in an assemblage (but it will only be an approximation because MNF is only an estimate of actual flake abundance). Since fragmentation can be shown to differentially affect flakes of varying shapes, sizes and raw materials (see [Hiscock, 1985](#)), the existence of standard measures of fragmentation should prove valuable in studies of debitage variability. Judicious use of these two counts should therefore not only assist analysts to quantify flake abundance but also help to explore the factors contributing to assemblage composition.

Further Considerations

Since flakes are the dominant component in virtually all flaked artefact assemblages the MNF index is clearly a key to examining abundance. Nevertheless, flakes are not the only category of flaked stone artefact likely to be recovered, and consequently NAS may exceed MNF not only because of fragmentation of flakes, but also because of the NAS count includes the non-flake component of the assemblage. One simple response to this would be to develop a more restrictive specimen count, one that would only incorporate flakes and flake fragments and is therefore a subset of NAS. We might term such an index, the Number of Flake Specimens (NFS) to denote that it is flakes alone rather than all stone artefacts being counted. Recognizing flakes and fragments of flakes in this context would require the identification of at least a portion of a ventral surface. By eliminating variation caused by differences in the abundance of non-flake classes of artefact the NFS count might technically be more appropriate than NAS for many comparisons with MNF. Hence much of the foregoing discussion of NAS:MNF ratios might actually be better framed by substituting NFS for NAS to provide NFS:MNF ratios. Since both NFS and MNF can be unambiguously defined and measured in highly repeatable ways, the use of these counts has many advantages.

While the NFS:MNF approach is tempting for many purposes, the restricted focus (i.e., only flakes) may mean it is not always acceptable. Consequently it would be useful to have a minimum number estimate for the non-flake component, to act as a companion to MNF. Since this is a technological rather than a typological issue, this reference to non-flakes does not refer to “implements”, most of which are usually retouched flakes and can be dealt with by the application of an MNF count. Indeed a count of $MNF_{retouch}$ may in some situations provide a minimum implement count (although this will depend on the nature of typological systems in use). The main category of flaked stone not dealt with by MNF will be

technical cores: rocks from which flakes have been removed thereby creating a piece with negative scars but no ventral surface (see [Hiscock, 2001](#)). Calculating a Minimum Number of Cores (MNC) index for such specimens is less straightforward than an MNF count because core fragments do not contain unambiguous reference points. For example a fragment of a core created by heat shattering could contain as little as a portion of one negative flake scar or as much as several dozen complete scars; and the number of such fragments deriving from a single core will be highly variable. As a consequence it is difficult to develop a single procedure for counting MNC. Obviously any count will be compiled as “complete cores + (core fragments/k)”, where k is an assemblage specific estimate of core fragmentation. Estimations of k might be based on different information for different assemblages. For example, mean weight for complete cores divided by mean weight of core fragments would be a simple way of deriving such an estimate.

If an appropriate MNC index can be devised for a particular setting then in that situation it can be added to the MNF count to produce a Minimum Number of Artefacts (MNA) index. Since an MNA index so derived would provide an estimate of the minimum flaked artefacts represented by the assemblage this might profitably be used in contrast to simple specimen counts in the form of a NAS:MNA ratio.

Conclusion

Counting stone artefacts is considerably more troublesome than is sometimes acknowledged. It is rare that all flaked artefacts are complete and abundance can be unambiguously established simply by counting the specimens. More often an assemblage has been subjected to processes that inflate the number of specimens, such as fragmentation, and/or processes that deflate the number of identified specimens, such as weathering. As a basic component of artefact analysis, abundance estimation must recognize the existence of these processes and develop estimation procedures that can measure their effects. To this end a number of counting procedures have been outlined (see [Table 1](#)) and their relationships and possible interpretations explored. Although the value of these estimation procedures were illustrated using artefact assemblages from Australia they should be generally applicable to any assemblage of flaked artefacts. It is suggested that the use of all of the indices will facilitate discussions of assemblage variation.

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