6

MOUNTAINS AND MOLEHILLS: SAMPLE SIZE IN ARCHAEOLOGICAL MICROSCOPIC STONE-TOOL RESIDUE ANALYSIS

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ABSTRACT

The passing of Thomas H. Loy in late 2005 presents an opportunity to reflect on the field of archaeological stone-tool microscopic residue analysis, of which Loy was a pioneer. This paper discusses one important and neglected aspect of residue studies from an historical perspective: reliance by residue analysts on small sample sizes. A review of stone-tool microscopic residue studies published over the first 30 years of the discipline (1976-2006) demonstrates that half of these examined 25 or fewer artefacts, with sample sizes of three or fewer artefacts being most common. In addition, sample sizes are shown to be decreasing in recent years. These findings have implications for the applicability of the novel data provided by residues to broader archaeological debates, and are discussed in relation to the specialisation of archaeological microscopic residue analyses. The review provides a caution against over-interpretation and emphasises the need for a more explicit link between sample sizes and research questions, while recognising the validity and usefulness of appropriately theorised studies of small numbers of artefacts.

KEYWORDS

residue analysis, microscopy, sample size, stone tools, Thomas H. Loy

INTRODUCTION

The passing in October 2005 of a pioneer of archaeological microscopic residue analysis, Thomas H. Loy, offers an opportunity to reflect on the historical trajectory of the field. Although building on earlier traceological work exemplified by Semenov (1964), the traditional origin date of the stone-tool microscopic residue technique is 1976, with the publication by Briuer of 'New clues to stone tool function: plant and animal residues' in *American Antiquity*. This was followed by the initiation of rigorous and multi-stranded investigation of blood residues by Loy (1983) and subsequent increased emphasis on starch grain residues and other plant microfossils (e.g. Loy *et al.* 1992). The residue analysis field is presently characterised by a growing diversity of approaches and geographic foci and extends to a time depth of well over 1,000,000 years (Dominguez-Rodrigo *et al.* 2001; Hardy and Rogers 2001), with this success owing in no small measure to Loy's influence.

This paper does not intend to provide an exhaustive historical overview, however, and instead takes this opportunity to examine a neglected issue of significance to current practice, namely the sample sizes employed by stone-tool residue analysts. This issue is discussed in the

context of the role of novel scientific data within archaeological reconstructions, using a review of the archaeological microscopic stone-tool residue literature from 1976-2006. The aims of this review are twofold: first to ascertain the range of variation and any trends in the numbers of artefacts examined by analysts; and second to ask whether or not sample size has or should have a constraining influence on the conclusions drawn from a stone-tool residue study.

SAMPLE SIZE IN MICROSCOPIC STONE-TOOL RESIDUE ANALYSIS

Sampling issues have a long tradition in archaeological investigation (see outlines in Baxter 2003; Mueller 1975; Redman 1974; also Orton 2000). To assess residue study sample sizes for this study, an annotated list of stone-tool microscopic residue analyses published between 1976 and 2006 was assembled (see Appendix). Certain parameters were followed for inclusion, namely that the residue data must be from a published account of original research on archaeological stone artefacts using light microscopy. This excludes therefore publications that discuss residue findings but report no new results (e.g. Denham and Barton 2006; Villa *et al.* 2005; Wood 1998), as well as unpublished theses and manuscripts (e.g. Broderick 1982; Fullagar 1982; Furby and Loy 1994; Gorman 2000; Higgins 1988; Loy *et al.* 1999; Paull 1984; Petraglia *et al.* 2002) and residue studies not employing, or ambiguous about the use of, light microscopy (e.g. Anderson 1980; Anderson *et al.* 2004; Anderson-Gerfaud 1990; Cosgrove 1985; Loy and Nelson 1986; McBryde 1974; Morwood 1981; Nelson *et al.* 1986; Potter 1994; Robertson 1996). Care has also been taken to avoid double listing of separate publications that report the same results (e.g. Dodson *et al.* 1993 and Furby *et al.* 1993; Fullagar 1988 and 1989; Fullagar 1992 and Fullagar *et al.* 1998; Pearsall 2003, Pearsall *et al.* 2004 and Chandler-Ezell *et al.* 2006; Perry 2002 and 2005) and in these situations the more detailed study is listed.

The studies reviewed were from the English-language literature, as the vast majority of residue results have been published in English, although a limited number of studies exist in other languages (e.g. Babot 2001; Pagan Jimenez *et al.* 2005). The Appendix to this paper updates that provided in Haslam (2006b: Appendix 1), and the literature surveyed covers only those publications available up to the time of data compilation in mid-2006. A small number of publications appearing around or after this time are therefore not included. These restrictions are not expected to affect the conclusions of the survey to any significant degree, however the dynamic nature of the field emphasises the need for periodic review.

The key concern of most researchers using sampling theory is obtaining a representative sample that will allow quantification and extrapolation of results from a limited dataset to a larger (often unknown) population. A relevant distinction here is between target and sampled populations (Orton 2000:41), the former being the set of artefacts about which we wish to make statements, and the latter being the available artefacts from which we select pieces for analysis. The very notion of sampling implies a target population under investigation, although the myriad approaches for analysing archaeological objects may require a narrowing or broadening of this target depending on the interests of the archaeologist. If the sampled population contains biases (e.g. all analysed stone tools are from one site), then it may not be possible to make meaningful statements about a wider target population (e.g. the use of stone tools across all sites in a region). It is also difficult to assess the validity of statements about any population when sampling procedures are not explicitly discussed in published studies, as is the case for the large majority of those reviewed for this paper. For example, while the artefacts in Haslam (2003) were randomly selected, this fact was not reported in the published study, which simply lists the number of artefacts examined. Non-random sampling introduces further potential biases.

Data from the studies reviewed in the Appendix suggest that stone-tool microscopic residue analyses have yet to adequately address or account for the influence of sampling biases, or establish representative samples appropriate for the desired scale of analysis. Clearly, there have been both large (>2000 artefacts, e.g. Boot 1993; Briuer 1976) and very small (single artefact, e.g. Babot and Apella 2003; Fullagar 1993b; Loy 1985; Piperno, *et al.* 2004) samples investigated.

Table 1. Summary statistics for the reviewed studies

All studies			
Total no. of studies	96	Standard deviation	420.34
Total no. of analysed artefacts	13025	Median	26
Mean no. of artefacts per study	135.68	Mode	3
24 largest studies		24 smallest studies	
Total no. of analysed artefacts	11514	Total no. of analysed artefacts	62
Mean no. of artefacts per study	479.75	Mean no. of artefacts per study	2.58
Standard deviation	750.93	Standard deviation	1.41
Median	166.5	Median	3
Mode	150	Mode	3

Statistical analyses and graphical presentation of these numbers provide an initial perspective on the representativeness of the conclusions drawn from these studies. Table 1 outlines some basic descriptive statistics; as it examines sample sizes those studies not reporting such data are excluded. Where multiple studies are reported in a single paper they are treated separately, as indicated in the Appendix, giving a total of 96 sites in 91 publications. The table includes information on the entire selection as well as the 24 smallest and largest studies (comprising 25% of the total in each case) as a means of further clarifying the nature of the data.

The most obvious feature of the data is that the sample sizes are very heavily positively skewed (that is, towards small samples), as seen in the sequence of mean>median>mode. This is true of the sample as a whole as well as for the largest 25% of studies. Data for the smallest 25% of studies show a very slight negative skew in the sequence of mean<median=mode, but as the largest sample size in this data subset is five artefacts, this does not detract from the observed trend towards analyses of small samples. The most common sample size in the entire dataset (the mode), and therefore the most commonly reported microscopic residue artefact sample size, is three artefacts. The second most common sample size is a single artefact, and the third most common is two artefacts. Similarly, while the overall average is 136 artefacts per study, this figure is deceptive, as the standard deviation of 420 (more than three times the mean), and the median value of 26 clearly show. The influence of the higher outliers is also seen when the largest 25% of studies are considered, with one standard deviation (751) far exceeding the mean (480). Half of all studies have examined 25 or fewer artefacts.

The largest 25% of studies contains every residue study of over 70 artefacts and the chief impact on this dataset is made by the three studies (Boot 1993; Briuer 1976; Fullagar 1988) that exceed 1000 artefacts. Because of the strong positive skew, a more realistic view of past practice is provided by the smallest 25% of studies, with a mean sample size of 2.6 and standard deviation of 1.4. By way of comparison, the smallest 50% of studies have an average of 8.6 artefacts per study, again with a relatively large standard deviation of 7.2 (data not shown in Table 1). Additionally, the total number of stone artefacts examined microscopically for residues over the past three decades may be estimated at less than 15,000 worldwide, even allowing for those studies that are not included in Table 1 due to lack of published data. The three largest studies contribute over 7000 of these artefacts. Compared with other archaeological analytical methods and other lithic analysis techniques, the low total number of artefacts analysed and published globally to this point marks the field as a niche provider of archaeological information, and the focus on small samples warrants further investigation for its impact on the field.

Graphic presentations of numerical trends are more accessible than raw statistics alone, so these are combined in the remainder of this section. Figure 1 shows the spread of published sample sizes, with the x-axis presenting two different scales divided at the 400 artefact mark for practical reasons. Studies smaller than 400 artefacts are mapped within 20-artefact bands,

beginning with 1–20 artefacts (represented as ‘20’ on the x-axis), then 21–40 artefacts, and so on. After the 381–400 artefact bracket (represented as ‘400’ on the x-axis), the studies are shown in 200-artefact bands in order to incorporate the few very large studies. The indication ‘600’ on the x-axis therefore represents the 401–600 artefact bracket, and so on up to 2601–2800 artefacts. Figure 2 breaks down the dominant ‘1–20 artefact’ category to reveal the emphasis on samples of three artefacts or fewer.

In addition to reviewing sample sizes by individual study, it is also beneficial to consider trends over time. In the following it should be stressed that phrases such as ‘artefacts analysed per year’ are used interchangeably with ‘artefacts published per year’, as it is rarely possible

Figure 1. Number of stone artefacts analysed per stone-tool microscopic residue study, 1976–2006.

Figure 2. Number of stone artefacts analysed per microscopic residue study, 1976–2006 (1–20 artefact sample sizes only).

to differentiate year of analysis from year of publication. The issues considered here, then, include the number of publications per year reporting original stone-tool microscopic residue results (Figure 3), the cumulative number of authors contributing to these publications (Figure 4), the number of artefacts examined per year worldwide (Figure 5), and the median sample sizes for analyses published each year (Figure 6). The former two graphs support the contention that the field is expanding and, while not all the authors included in Figure 4 are themselves residue analysts, this trend does show the rapidly increasing number of archaeologists willing to incorporate microscopic residue data into their work. Figure 4 is conservative in that publications discussing residues but not presenting new data are not included in the surveyed literature for this paper; however trends toward multiple authorship counter this conservatism somewhat.

Figure 3. Number of publications reporting original results of microscopic stone-tool residue analyses per year, 1976-2006.

Figure 4. Cumulative total number of authors who have published original microscopic stone-tool residue results, 1976-2006.

Figure 5. Number of stone artefacts analysed for microscopic residues per year, 1976-2006. Years marked with ‘+’ have values beyond the range of the graph (1976 n=2551; 1988 n=1814; 1992 n=1263; 1993 n=2798; 2004 n=1687).

Figure 6. Median number of analysed artefacts per stone-tool microscopic residue study, 1976-2006. Years marked with ‘+’ have values beyond the range of the graph (1976 n=2551; 1988 n=1814).

Figures 5 and 6 present two different perspectives on chronological quantification. Since 1976, five years have seen more than 700 artefacts analysed (Figure 5), largely attributable to the actions of individual researchers (Boot 1993; Briuer 1976; Fullagar 1988, 1992; Hardy 2004; and Williamson 2004, Wadley *et al.* 2004). Other than these exceptional occurrences, global residue research output is measured in the hundreds, and in many recent years the tens, of artefacts annually. There are however no striking trends in this highly variable data, even if a speculative ‘pulse’ of activity on a roughly five-year cycle is discerned over the past 20 years or so. Additionally, the

figure for 2006 in this chart would be expected to increase with the inclusion of data from the latter part of that year. Figure 6 provides a valuable alternate viewpoint, displaying median annual sample sizes rather than means (which simply tend to follow a scaled-down version of the data in Figure 5) in an attempt to avoid the skew created by extreme outliers at the higher end of the scale. Two years (1976 and 1988) are again off the chart as they saw only one large published study each. Interestingly, once the field moved beyond its introductory phase and established itself in the late 1980s (the last year without at least one publication reporting an original set of light microscopy residue results was 1986; see Figure 3), there has been a slow and uneven but nevertheless relatively steady decline in median sample sizes. Note that unlike the totals in Figure 5, median values for the first half of 2006 are valid as they are independent of the number of studies. With only one exception, each year from 1988 to 1998 inclusive the median sample was above 20 artefacts per study; since 1998 the median has not exceeded this number. Importantly in this regard, 41 of the 91 publications (45%) surveyed for this review were published since 1998, forming a significant component of the residue literature currently contributing to archaeological debate. Implications of declining sample sizes for archaeological interpretation are discussed further below.

A final approach to the data (Figures 7 and 8) is based on geography rather than sample size, and again illustrates the strong influence of a few individuals in the growth of the residue field. Microscopic stone-tool residue analyses have to date been completed by researchers working in a number of countries, however these may be divided into four broad geographic locations for the purposes of initial assessment – Oceania (principally Australia and Papua New Guinea), the Americas (especially North and Central America and northern South America), Africa (chiefly South Africa) and Eurasia. In reporting the numbers of artefacts analysed for each of these regions, I have broken the 30-year period since 1976 into five-year blocks (note that for the sake of inclusiveness the few studies from the first part of 2006 have been included in the final block). It is apparent from Figure 7 that initial application of microscopic residue analysis occurred in the Americas, and was followed subsequently by rapid growth in Oceania, and more recently South Africa. Studies of Eurasian material (with a focus on western Europe and the Middle East) have not seen the same expansion in terms of studied artefacts but have nonetheless continued steadily since their inception in the late 1980s.

As seen earlier the presence of large outlier studies is a strong influence and in this instance is directly related to the geographic focus of key analysts: Briuer initially in North America, Fullagar and Boot in Australia/Papua New Guinea, Hardy and Loy in Europe and Williamson in South Africa. It is worth noting in the context of this volume that Loy was responsible for training and/or early collaboration with many of these researchers, indicating the high impact (quantitatively and pedagogically) of individuals in shaping a field with relatively few practitioners. Interestingly, after 1990 a decline or plateau in numbers of analysed artefacts occurs in Oceania and the Americas alongside growth in Eurasia and Africa, despite increases in the numbers of studies published in all regions over the same period (Figure 8). A pattern of initial examination of large samples, perhaps as a form of method validation or training, followed by fragmentation into a variety of much smaller analyses is therefore apparent for the Americas, Oceania and to a lesser extent Eurasia. Whether this pattern will hold for Africa remains to be seen.

REPRESENTATIVENESS AND STATISTICAL SIGNIFICANCE

Having briefly considered the trends in typical sample sizes employed in stone-tool microscopic residue analysis, we may now consider the relevance of this information for archaeological interpretation. In general, for any project the impact of sample size on the inclusiveness or representativeness of results is dependent on the question asked, the target population, and the qualitative or quantitative nature of the enquiry. Piperno *et al.* (2004) for example examined a single grindstone, yet the provenance (Upper Palaeolithic Israel) and observed residues (starches indicative of barley processing) warranted publication in a prestigious scientific journal. There is no

Figure 7. Number of stone artefacts analysed for microscopic residues per 5-year period, by geographic region.

Figure 8. Number of published stone-tool microscopic residue studies per 5-year period, by geographic region.

need, and in fact it is somewhat counter-intuitive, to extrapolate the results of the earliest evidence for grass-seed processing to other sites or artefacts. The unspoken, but correct, assumption in this situation is that the implications for our understanding of past social organisation, dietary shifts and economic factors behind the use of a single artefact are profound enough to warrant publication. The routine residue analysis of non-descript artefacts that do not have a proxy importance gained through age, location or rarity may require justification in other terms, especially when choices are made as to which sites will be analysed and which cannot due to financial and time constraints. At the same time, it is usually the non-descript, ‘everyday’ artefacts that are most prevalent and available for study, even though these may appear essentially identical in potential information content from site to site in a given region. Factors other than perceived importance may also

influence sampling decisions – for example artefacts of limited typological or display value may escape rigorous cleaning and therefore provide more appropriate candidates for residue study. The key is to ensure that the questions asked and the conclusions drawn are both relevant for the actual pieces of stone examined.

At the heart of the matter is a simple question: is it possible or meaningful to talk of a ‘valid microscopic residue analysis sample size’? In this sense statistics may provide some guidance. The point at which a randomly selected sample from an unknown population size (the case for the vast majority of archaeological material) becomes statistically significant can be calculated for a number of confidence levels. The most common confidence level employed by archaeologists is 95%, although at its base this is an arbitrary choice (Cowgill 1977). The data generated by residue analysts can be considered categorical (non-numerical), in that there is no justifiable basis yet established for treating, for example, the presence of 15 starch granules or collagen fibres on a used tool edge as being meaningfully different to finding 12 or 30 granules or fibres on that edge, thanks largely to taphonomic factors. In addition, as studies often report the proportions of various residue types and inferred uses of analysed artefacts (e.g. Fullagar 1992; Lombard 2008), the following equation can be used to calculate the number of artefacts that must be examined to make statements of statistical significance for a particular confidence level (Drennan 1996):

$$n = \left(\frac{\sigma t}{ER} \right)^2$$

where n = the required sample size.

σ = the standard deviation of the sample.

t = the Student’s t distribution value for the desired confidence level.

ER = the error range (or confidence interval) for the sample.

Using proportional data, the standard deviation is found by:

$$\sigma = s = \sqrt{pq}$$

where p = the proportion of artefacts expressed as a decimal fraction; $q = 1-p$.

If the proportions of artefacts used for various tasks are unknown to begin with (again typical in residue studies) then the most conservative guess of 50% can be used (Drennan 1996:143). This guess means that if there is any variation from 50%, the resulting error ranges will be smaller than those calculated — in other words the result will only become more precise. This information can be used to calculate the number of artefacts that must be examined to make a statistically valid statement about the inferred tasks represented by those artefacts. Using the t value (1.96) associated with the standard 95% confidence level for a large unknown population size, an error range of $\pm 5\%$, and a proportion of 50%, then:

$$\sigma = \sqrt{pq} = \sqrt{(0.5)(1-0.5)} = 0.5$$

and

$$n = \left(\frac{(0.5)(1.96)}{0.05} \right)^2 = 384.16$$

To summarise, an analyst is required to examine 385 artefacts randomly selected from a given context to be able to speculate on the representativeness of their (categorically-described) residue

findings for that context at a 95% confidence level. Of the 91 studies listing sample sizes in the Appendix, only eight exceed this figure. If an analyst wishes to divide their sample, for example into different temporal periods or spatial areas, each of those divisions would require 385 artefacts to make assertions at this confidence level, provided of course that the requisite number of artefacts were recovered. As a point of comparison, 25 of the studies in the Appendix analysed sufficient artefacts to assert statistical significance at the 90% confidence level (requiring 68 artefacts with a $\pm 10\%$ error range), and 66 had a sufficient sample to assert statistical significance at the 80% confidence level (requiring 11 artefacts with a $\pm 20\%$ error range). None of these studies contain statistical calculations of significance for the findings they report. In fairness, while heuristically valuable, confidence levels are not fixed boundaries that decisively assign a given study into a box labelled either 'true' or 'false' (Ringrose 1993), and as noted even one artefact may supply a wealth of information. The important point is for residue analysts to apply appropriate statistical reasoning, at appropriate times, to support and strengthen their conclusions.

The misuse of or blind faith in statistical analyses has been identified by Cowgill (1993:552-553) as one of the major shortcomings of archaeological processualism, while at the same time commenting that 'Quantitative techniques can be treated lightly only if one believes that remains of the past themselves have little bearing on our judgements about the merits of different stories'. To muddy the statistical waters further, there is also no necessary correlation between the number of artefacts analysed in a given study and the number with identifiable and interpretable residues. For example, Briuer's (1976) analysis, the first reported stone-tool microscopic residue study and still the second largest, found identifiable organic use residues on 37 (or 1.5%) of 2551 analysed flakes. With residue studies in their infancy, however, Briuer may have missed or been unable to identify residues that would now be routinely recorded. The largest reported study to date (Boot 1993) found 165 hafting or use residues on 2722 artefacts (6%); the third largest (Fullagar 1988) found residues on 13 of 1814 artefacts (0.7%). Much higher rates have been reported from other studies, including the early work of Loy (1983) who reported blood residues on 90 of 104 artefacts (87%). These results demonstrate that there is no sure ratio of analysed artefacts to artefacts with residues, a fact that may be intuitive but could cause problems if attempts at quantitative comparisons are made. These problems are compounded by variations in sampling rationale: artefacts for residue studies have been drawn randomly from the available assemblage (e.g. Haslam 2003); chosen selectively by the archaeologist as likely to have been used (e.g. Veth *et al.* 1997); chosen to cover a range of temporal periods and raw materials (e.g. Barton 1990); or the sample is the complete assemblage from a pit or site (e.g. Fullagar and David 1997). Attempting to compare inter-study percentage results of, for example, plant and animal processing tools (e.g. Boot 1999) may be inappropriate in light of these diverse sampling procedures.

The restrictions that small sample sizes impose on the broader applicability of results were recognised early on by Shafer and Holloway (1979:398), who noted that for their sample of 25 artefacts they 'fully realize the limited application of the overall findings regarding the use of tools in the assemblages being studied'. Fullagar (1987:26) likewise observed that in determining overall site function, 'for sites with very small numbers of tools, the proportion of materials worked may be meaningless', a sentiment which has obvious correlation with analyses of small samples, regardless of the assemblage size from which they are drawn. The majority of studies in the Appendix make no mention of a carefully reasoned sampling strategy based on a well-defined target population, which is either an omission in reporting protocols or evidence that the impact of sampling on the relevance and reliability of results has to this point largely been overlooked. It is also possible that the lack of explicit published sampling rationales correlates with indications that many stone-tool microscopic residue analyses may begin with an aim of simply 'finding out what's there' (Haslam 2006b), and only subsequently are the results broadened into discussions of, for example, regional subsistence practices (see Hardy and Svoboda [this volume] for an alternative to this scenario). The desirability of examining entire assemblages to produce defensible results was highlighted recently by Smith (2004:174) in a study of starch on grindstones, although the logistics of such a task often may be prohibitive. As microscopic residue

analyses have increasingly taken a central role in key world archaeological debates, especially concerning early plant domestication and food processing (Denham, *et al.* 2003; Fullagar and Field 1997; Fullagar, *et al.* 2006; Perry, *et al.* 2006; Piperno, *et al.* 2000; Piperno, *et al.* 2004), it is likely that sampling issues will play a correspondingly important role in further progressing the value of the field.

TARGETS AND SAMPLES, MOUNTAINS AND MOLEHILLS

Microscopic stone-tool residue analysis is time-consuming and expensive, and with current median values of less than 20 artefacts per study, there are clearly benefits in openly discussing the kinds of questions we want microscopic residues to address. If total-assemblage projects were to become the norm, then there would be few restrictions on research targets – everything from broad studies of non-lithic artefact production, prehension and cognitive processes to classification of artefacts by use rather than form (and much more) would be worth exploring. In the short-term, however, more may be gained from questions that maximise the value of small samples, and selectively target larger numbers of artefacts when required. For example, in recent years researchers in the Americas in particular (e.g. Perry *et al.* 2006) have established a solid research agenda concentrated on the variety of human-plant interaction, plant processing and settlement information to be gained from focused studies of starch residues, with an emphasis on ground stone artefacts. Alternatively, for non-descript stone pieces we may profitably consider the social roles of individual artefacts (Haslam 2006a; Haslam and Liston 2008). This approach relies on contextual data for one or a few artefacts (demonstrated above to be the most commonly analysed sample sizes) as an alternative to extrapolating results over a site or region. Recent investigations of South African hafting and hunting technologies (e.g. Gibson *et al.* 2004; Lombard 2005; Wadley *et al.* 2004) also demonstrate the interpretive value of a clear research focus, building a broad perspective from successive related studies.

Perhaps the most obvious way to bring sampling into a more prominent position within residue analysis is to re-examine existing studies, first determining the scale (target population) of the presented discussion, then comparing this with the quantity and contexts of the analysed artefacts. This task would take more space than is available here and is by no means straightforward; as a start however, questions arising from a few brief examples may be considered to introduce the concept. Consider first the recent work of Dominguez-Rodrigo *et al.* (2001) on East African Acheulian handaxes, a significant study reporting the oldest microscopic use-residues to date and rigorously documenting clear associations between tools and their residues over a very large time period. From a sampling perspective, then, we may begin by asking how many Acheulian handaxes need to be analysed before any generalisations about early human use of these tools can be made? Are the three analysed by Dominguez-Rodrigo *et al.* (2001:292), from one site dated to 1.4-1.7 million years ago, sufficient? What about thirty or three hundred, and across how many sites? The authors identified traces of woodworking residues on two of the three handaxes; to what extent can this finding be interpreted as showing ‘that humans, at a very early stage of their evolution, were producing wooden implements’ (Dominguez-Rodrigo *et al.* 2001:297-298), with implications for complex hominid intelligence? In broader contextual perspective, what role should wooden spears from Germany or England made more than one million years later have in strengthening hypotheses about early East African handaxe use for spear-making (Dominguez-Rodrigo *et al.* 2001:289, 298)?

A discussion of potential handaxe use for the continents and hundreds of millennia across which these artefacts are found is well beyond the scope of this paper, and the requisite functional analyses of representative samples from well-dated Acheulian assemblages divided into different environmental, geographical, hypothesised site-function and temporal zones is non-existent. Nevertheless, given the large numbers of handaxes currently in museum collections and a long history of functional speculation and investigation (e.g. Keeley and Toth 1981; Kohn and Mithen 1999; Shick and Toth 1993; Whittaker and McCall 2001) this artefact type would appear to be

an ideal target for a series of residue studies aimed at determining both basic population-wide use-data and the role of sampling in potentially biasing interpretations. We may ask, for example, if the proportion of plant to animal working tools seen in a given study varies independently of sample size, or is asymptotic for larger samples? Are there site- or region-specific patterns suggesting environmental and/or social influences on use? Were these artefacts even made for use as tools (Davidson 2002)? Dominguez-Rodrigo *et al.* have commendably established a necessary base-line for beginning to address such questions, but well-defined target populations are clearly required before broadening results beyond the site and time period examined.

Sampling concerns do not only affect such spatiotemporally vast constructs as the Acheulian, of course, and with this in mind we may examine a second important recent study. Perry (2005) successfully gathered both botanical and artefact functional data from starch analysis of five microlithic ‘manioc’ grater flakes from a Venezuelan site, providing excellent contextual information for the location some 1200-1500 years ago and demonstrating the range of activities for which these particular tools were employed. At the same time, Perry (2005:414) uses the results to evaluate ‘the validity of the direct historical approach in the interpretation of archaeological artifacts from the middle Orinoco valley’ by comparing the ethnographically-derived assumption of manioc grating to the actual tool functions observed microscopically. Again from a sampling perspective, the question at hand is whether the reported starch analysis of five artefacts, from one half of one level of a 1 m x 1 m test unit at one site, is sufficient for such an evaluation.

The Orinoco case study has relevance for all functional projects that attempt to test ethnographically-derived functional assumptions, and as the stated target is in this instance quite broad the sample ideally should be equally comprehensive. It is likely therefore that artefacts from a number of sites in the middle Orinoco and across a number of time periods leading up to the ethnographic present would require examination to judge the validity of the direct historical approach in this region. In the absence of such data it is difficult to judge the representativeness of the analysed pieces for the middle Orinoco assemblage. As a test, it seems reasonable to assume that a representative sample suitable for addressing the target question would be able to aid in identifying the point at which direct historical approach becomes valid, that is, when ethnographically-observed activities become the dominant ones for these microliths. The sample selected does not permit such an assessment. Perry has certainly demonstrated the inapplicability of the direct historical approach to interpreting her sample of five artefacts, and the extrapolation from this to the whole middle Orinoco may appear a minor one, but it is precisely the feasibility of such extrapolations that sampling designs make explicit. Tangentially, it could be asked whether narrowing the study’s discussion solely to statements relevant to the analysed artefacts and their immediate context may diminish its value, and therefore restrict the potential publishing venues. In other words, there is a tension between on the one hand the restrictions imposed in microscopic residue analysis by a time-consuming practical component, and on the other a requirement to make the results as useful to others as possible.

In these examples a case may be argued for both large and small-scale interpretation of limited sample studies, depending on the reader’s willingness to follow the author’s leap from sample to target. Similar issues, including extrapolation from single site analyses to regional patterns, and from precise reconstruction of limited individual tool use to broad generalisations about short or long term human activities are worth discussing for many of the studies conducted to date. That said, all projects progress sequentially over time, and small sample sizes addressing questions aimed at small, well-defined target populations are entirely valid. The key point is that archaeologists engaged in microscopic stone-tool residue studies have not been as stringent in our identification of target populations as we could be, and explicit demonstrations of how sampling strategies (of however many artefacts) tie back to a given target are often conspicuously absent. In a related issue facing all archaeologists, we may ask whether the use of qualifier terms such as ‘preliminary’, or phrases such as ‘hints at’ or ‘suggests’ rather than ‘demonstrates’, justify making claims beyond the significance warranted by the sample size? Use of such terms may be tempting, particularly in a field such as microscopic residue analysis where time and financial constraints

act to restrict the number of artefacts that may be examined, while as in any field publication pressures demand a high level of impact for the results. Equally important is the fact that residue analyses often produce striking results of specific tool-use that are likely to excite the imagination, perhaps contributing to an overstatement of significance. If care is not taken, however, results first reported as preliminary or speculative may after repetition come to be cited as reliable facts. Overall, the contribution of sampling theory to such issues is, as Orton (2000:206) points out, ‘in providing a language and a frame of reference within which such problems can be discussed, rather than definitive answers’.

What then are the prospects for augmenting current practices that emphasise many studies of few artefacts rather than vice versa? Apart from a need to improve the reporting of sampling strategies and to explicitly tie the scale of conclusions to the scale of analysis, several additional options are available. First, as mentioned earlier, a theoretical turn towards highly contextualised interpretation of individual actions offers an alternate path for residue results from a limited number of artefacts (Haslam 2006a). This approach is designed to provide a humanised and agent-centred past as a further line of investigation complementary to current research agenda, rather than to directly address the ‘big picture’ questions of archaeology, and it therefore provides a potentially valuable but only partial solution. A second approach is to conduct a series of dove-tailed research projects at the one site or region, which may then by accretion answer questions at successively larger theoretical and geographical scales. Excellent examples of this approach include Fullagar’s work in West New Britain, Williamson and more recently Lombard’s studies of Rose Cottage Cave and Sibudu Cave in South Africa, and Hardy’s work in Crimea.

One of the chief benefits of such long-term investment in particular sites and regions is that additional small-sample research may be justifiably incorporated into an established framework. Researchers working on well-studied sites, especially where lithic technological information is also available, are in the best position to identify relevant large-scale issues with which residue analysis may engage. The contributions to this volume by each of the researchers mentioned demonstrate that the necessary vitality exists in the field to generate productive discourse on this issue. As a natural corollary to this last point, where discussions of broad trends are a desired outcome then initiation of further projects that aim from the outset to examine significant proportions of a site or regional assemblage will be essential. And finally, a third path for increasing the scale of analyses without incurring significantly greater costs is to conduct initial rapid screening of artefact assemblages for residue-bearing artefacts. Subsequent sample selection from among those artefacts with clear residues avoids some of the problems noted earlier but introduces new challenges for relating the residue-bearing assemblage to the lithic assemblage and target population as a whole.

CONCLUSION

With a trend over the past decade toward smaller sample sizes, and typical samples measured in the tens of artefacts or less, sampling theory suggests that analysts should be implementing an accompanying constriction in the scale of conclusions drawn from microscopic stone-tool residues. In practice, such constrictions may be alleviated or overcome through explicit recognition of the limitations built into small-scale analyses. In this regard it would be insufficient, for example, to label a study ‘preliminary’ and then to disregard this fact in either the conclusions of that same study or in future publications. In comparison with lithic technological research in which many thousands of artefacts or complete assemblages are routinely recorded for a given site, it is perhaps surprising that microscopic lithic residue analyses have yet to come under greater scrutiny for their sampling practices, and in this regard the success of the technique may obscure its limitations somewhat. There are logistical impediments to the widespread use of a whole-assemblage approach to residues, however it is only through such projects that we gain the necessary baseline data against which the reliability of small-sample conclusions can be evaluated. Caution in interpreting small-sample studies and an explicit focus on the relative

merits of different sample sizes can only result in greater explanatory power and wider acceptance and integration for all microscopic stone-tool residue analyses.

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APPENDIX: ARCHAEOLOGICAL MICROSCOPIC ANALYSES OF RESIDUES ON STONE ARTEFACTS.

Year	Author(s)	Site, age (approx.)	# ¹	Mag. ²	U-w ³	Journal ⁴	Summary
2006	Mazza, Martini <i>et al.</i>	Campitello Quarry, Upper Valdarno Basin, Italy, Middle Pleistocene	3	0.74-70x	Y	JAS	Flakes examined via low-power analysis. Revealed traces of hafting resin on one artefact and abundant resin on another. Subsequent chemical analyses suggest <i>Betulaceae</i> trees as the origin of the resin/tar.
2006	Fullagar, Field <i>et al.</i>	Kuk Swamp, Papua New Guinea, <10,220BP	55	6-1000x	Y	JAS	Examined 55 artefacts to assess residue presence and preservation, then examined 12 artefacts for taro and yam starch specifically – 11 of these had starches.
2006	Haslam	Palau, Micronesia; Copan, Honduras	-	100-1000x	-	JAS	Few details on number or age of analysed artefacts. Identified fungal elements (conidia, hyphae) and noted the potential for confusion with starch granules.
2006	Perry, Sandweiss <i>et al.</i>	Waynuna, Peru, 3600-4000BP	3	200x	-	Nature	Starch removed from unwashed grindstones and separated with CsCl. Discusses plant use and migration from various microfossils. Identified maize, arrowroot and possible potato starches.
2006	Zarillo & Kooyman	Alberta, Canada, pre-European contact	3	400-630x	Y	Am Ant	Analysed two washed grinding tools and one flake tool. Starch from choke cherry, saskatoon and maize was identified, with tentative starch identification of prairie turnip and Graminae
2005	Lombard	Sibudu Cave, South Africa, 51-62ka	50	50-500x	Y	JHE	Identified various plant, animal and mineral residues, including hafting resins. Posited hunting tool-use.
2005	Perry	Pozo Azul Norte-1, Venezuela, 1200-1500BP	7	10-400x	Y	LAA	Identified starches on quartz microliths; testing interpretations of microlith use based on ethnohistoric records.
2005	Weisler & Haslam	Molokai, Hawaii, 300-400BP Henderson Is. Pitcairn Group, 400-1000BP	14 15	100-1000x	Y	HA	Studied small volcanic glass flakes from two Pacific islands in an initial cataloguing of past uses. Found plant tissue, feather, starch. Uses identified are not assumed to be universal.
2004	Fullagar & Jones	Rocky Cape, Tasmania, Australia, 6.7ka	150	50-500x	Y	AO	Identified 43 used artefacts with residues present including general plant tissue, wood, starch, skin, and bone. Some discussion of activity areas.
2004	Gibson, Wadley <i>et al.</i>	Rose Cottage Cave, South Africa, 60-68ka	48	50-800x	Y	SAH	Identified plant tissues, blood, ochre and modern contaminants. Starch grains were present on all artefacts. Discussion of hafting.

Year	Author(s)	Site, age (approx.)	# ¹	Mag. ²	U-w ³	Journal ⁴	Summary
2004	Hardy	La Quina, France, ca. 40-70ka	300	50-500x	Y	Antiquity	106 artefacts had residues, which included plant tissue, pollen, raphides, hair, bone feather and possible blood. Plant residues observed on 10 of 16 previously washed tools. Discussion of plant vs animal exploitation.
2004	Iriarte, Holst <i>et al.</i>	Los Ajos, Uruguay, 3500BP	3	100-400x	-	Nature	Maize starch granules (total n=17) recovered from 3 milling stones. Methods reference Piperno <i>et al.</i> (2000).
2004	Lombard	Sibudu Cave, South Africa, 51-61ka	24	50-500x	Y	SAAB	Uses floral and faunal residue distributions to infer hafting and subsistence activities (i.e. hunting)
2004	Pavlides	Yombon, West New Britain, late Pleistocene	3	-	Y	-	In <i>A Pacific Odyssey</i> . Few details provided, but plant processing (wood/starch) identified.
2004	Pawlik	Bornheim-Sechtem, Rhine Valley, Germany, 3500BP	1	-	Y	-	In <i>Lithics in Action</i> . Flint artefact from a grave site identified as a 'prehistoric pocket lighter' through light microscopy and subsequent SEM-EDAX of the tool and an associated haematite fragment.
2004	Pawlik	Ullafelsen, Tyrolian Alps, Austria, 10.5-11ka Henauhof-Nord II, Germany, Mesolithic	110 -	-	Y	-	In <i>Lithics in Action</i> . 25 siliceous artefacts from Ullafelsen had tar-like hafting residues identified by light microscopy. SEM subsequently used to characterise the tar. No magnification data. No data on number of artefacts from Henauhof-Nord – these artefacts also had hafting residues with embedded plant fragments visible using SEM.
2004	Pearsall, Chandler-Ezell <i>et al.</i>	Real Alto, Ecuador, 2400-2800BP	17	312-500x	-	JAS	Samples collected by brushing, washing and sonication from ground stone and cobbles. Maize starch recovered from all tools; most effective method was sonication. Some starch separated with CsCl. See also Pearsall (2003) and Chandler-Ezell <i>et al.</i> (2006).
2004	Perry	Orinoco valley, Venezuela, 500-1000BP	10	10-400x	N	JAS	Studied ground stone and flake tools, by microscopy and removal of residue by spot sampling and sonication. Identified arrowroot, maize, ginger and grass (Poaceae) starch. Results compared with macrobotanical remains.
2004	Piperno, Weiss <i>et al.</i>	Ohalo II, Israel, 22.5-23.5ka	1	400x	N	Nature	Starch grains identified in residue removed from a grindstone. Identified grass-seed starches, including <i>Hordeum</i> sp. Earliest direct evidence for human grass-seed processing.

Year	Author(s)	Site, age (approx.)	# ¹	Mag. ²	U-w ³	Journal ⁴	Summary
2004	Rots & Williamson	Southern Ethiopia, modern	18	50-800x	Y	JAS	Compared ethnographic with archaeological scrapers. Found very few residues on the archaeological tools, including starch, blood and ochre.
2004	Slack, Fullagar <i>et al.</i>	Old Lilydale Homestead (OLH), QLD, Australia, 15ka;	1	200x	Y	AO	Backed artefacts; few specific details of the residue study are provided, however. Found starch and 'dark smears' on the OLH tool, and greasy films and starch granules on one of the GRE8 tools.
		GRE8, QLD, Australia, 15ka	2				
2004	Smith	Puritjarra rock shelter, NT, Australia	56	10-625x	Y	-	In <i>Archaeology From Australia</i> . Examined grindstones for starch. Also tested for blood (with Hemastix) and plant alkaloids. Observed starch most closely matched acacia; starch was also observed in abundance on non-cultural gravels and in site sediments.
2004	Wadley, Williamson <i>et al.</i>	Sibudu Cave, South Africa, 26-60ka	531	50-800x	Y	Antiquity	Focused on ochre residues, also observed plant residues (e.g. tissue, fibres, starch, exudate).
2004	Williamson	Sibudu Cave, South Africa, Middle Stone Age	412	50-800x	Y	SAJS	Residues found include starch, collagen, blood, ochre, fungi, hair, plant tissue. Results discussed in terms of plant vs animal processing.
2003	Babot & Apella	Tucuman, Argentina, 1.5-2ka	1	400x	N	Archaeometry	Maize starch identified on a grindstone, in conjunction with ground bone residue.
2003	Denham, Haberle <i>et al.</i>	Kuk Swamp, Papua New Guinea, 6.5-10ka	3	-	Y	Science	Identified <i>Colocasia esculenta</i> (taro) starch. Very limited report – does not include microscope or magnification information, or provide photographs.
2003	Haslam	Copan, Honduras, 1900-2050BP	150	100-1000x	Y	-	In <i>Phytolith and Starch Research</i> . Maize residues identified on obsidian and other artefacts via starch grains and plant tissue.
2003	Lu	Zengpiyan, China, 7-12ka	80	-	Y	-	In <i>Zengpiyan-A Prehistoric Cave in South China</i> . 80 pebble tools examined for starch. Grass family and taro starch found on 11 tools.
2003	Van Peer, Fullagar, <i>et al.</i>	Sai Island, Sudan, 180-220ka	2	-	Y	JHE	Very little information provided. Phytolith and starch granules in residues removed from quartzite cobbles.
2002	Akerman, Fullagar <i>et al.</i>	Keep River region, NT, Australia, late Holocene	15	100-1000x	Y	AAS	No specific dates reported. Identified resin, ochre and plant tissue. Archaeological results are discussed in conjunction with residue study of ethnographic material.
2002	Risberg, Bengtsson <i>et al.</i>	Various sites, Sweden, 4.6-5.7ka	6	1000x	Y	JNAS	Grindstone residues from three sites examined for siliceous particles (e.g. diatoms, phytoliths) and starch.
2002	Robertson	Deep Creek Shelter, NSW, Australia, 1-3.5ka	41	6-1000x	Y	Tempus	Only feather residues reported for these artefacts, although other residues were present (see Robertson 2005).

Year	Author(s)	Site, age (approx.)	# ¹	Mag. ²	U-w ³	Journal ⁴	Summary
2001	Balme, Garbin <i>et al.</i>	Puntutjarpa Rockshelter, WA, Australia, modern-10ka	49	50-800x	Y	AA	Grindstone study. Most tools had starch residue, some had blood, ochre, hair, plant fibres. Results discussed in terms of seed grinding.
2001	Dominguez-Rodrigo, Serrallonga, <i>et al.</i>	Peninj, Tanzania, ca. 1.5Ma	5	400x+	N	JHE	Identified siliceous phytoliths, calcium oxalate crystals and plant tissues on the artefacts and surrounding soils. Suggest a woodworking function for handaxes.
2001	Hardy, Kay <i>et al.</i>	Buran Kaya III, Crimea, Ukraine, 32-37ka	19	100-500x	Y	PNAS	Evidence of hafting and use on plants and animals. Residues include hair, feathers, plant tissue, starch grains, raphides. Some discussion of plant vs animal use. This study also re-presents some of the residue results from Hardy (1998).
2001	Turner, Anderson <i>et al.</i>	Emily Bay, Norfolk Island	15	10-1000x	Y	RAM	No dates provided. Analysed 10 basalt, 5 obsidian artefacts. 4 artefacts had starch (<1 µm). Some plant tissue residues.
2000	Green & Anson	Kainapirina (SAC), Watom Island, Papua New Guinea, 1850-2400BP	-	-	Y	NZJA	Very little information provided. Highly weathered obsidian was studied, resulting in little residue (or use-wear) information. See Hanslip (1999).
2000	Piperno, Ranere <i>et al.</i>	Aguadulce shelter, Panama, 5-7ka	19	100-400x	N	Nature	Grindstone study, using CsCl extraction. Manioc, yam, arrowroot and maize starch identified. Earliest direct evidence for root crop cultivation in the Americas.
1999	Davis	Mleiha, United Arab Emirates, 0-2200BP	17	500-1000x	Y	-	In <i>Mleiha</i> . Water extraction from ground stone artefacts. Starch found on all artefacts. Possible Hordeum or Triticum starch recovered.
1999	Kealhofer, Torrence <i>et al.</i>	FAO, Garua Island, West New Britain, Papua New Guinea, modern-5900BP FRL, West New Britain, Papua New Guinea, modern->10ka	3 14	6-500x	Y	JAS	For both sites, independent use-wear and phytolith studies assessed the value of phytolith residue analysis. Identified collagen, starch, fibres, resin, phytoliths. Results used to discuss changes in tool use over time.
1999	Shanks, Kornfeld <i>et al.</i>	Bugas-Holding, Wyoming, USA, 200-500BP	46	50-100x	Y	JAS	17 tools displayed visible microscopic residues, recorded as presence/absence only. Immunological tests for blood then carried out.
1998	Atchison & Fullagar	Jinmium, NT, Australia	3	500x	-	-	In <i>A Closer Look</i> . Examined three grinding tools for starch by water extraction and removal to microscope slide. Dates uncertain.
1998	Attenbrow, Fullagar <i>et al.</i>	SE Australia, <900BP	28	10-1000x	Y	-	In <i>A Closer Look</i> . Examined stone 'fish-hook files' for evidence of shell-working. Found some shell residues, also plant.

Year	Author(s)	Site, age (approx.)	# ¹	Mag. ²	U-w ³	Journal ⁴	Summary
1998	Barton, Torrence <i>et al.</i>	Garua Is., Papua New Guinea, 200-5000BP	14	200x	Y	JAS	Residues removed from obsidian artefacts by sonication, as a concurrent use-wear 'blind test' was being conducted. Starches quantified but not identified.
1998	Brass	Kafiavana, Papua New Guinea, <10.7ka	200	6-1000x	Y	-	In <i>A Closer Look</i> . Identified residues in four categories – plant, blood, plant/blood and undiagnostic. Blood tested by subsequent Hemastix and immunology. 'Plant' includes starch and plant fibres.
1998	Garling	Cuddie Springs, NSW, Australia	4	100-500x	N	-	In <i>A Closer Look</i> . Microscopy used to identify possible blood residues, then haemoglobin crystallisation used to attempt species identification. No dates provided.
1998	Hardy	Starosele, Crimea, Ukraine, 40-80ka	116	100-500x	Y	-	In <i>The Middle Paleolithic of the Western Crimea</i> . Residues classified initially as plant/animal. Identified starch, plant tissue, raphides, possible mastic, hair and feather. See Hardy and Kay (1998) for combined discussion of use-wear and residue results.
1998	Loy	Hauslabjoch, Italy, 5300BP	6	50-1000x	Y	NS	Identified feather, blood, hair, collagen, plant hairs on the stone component of the toolkit of Otzi the Iceman.
1998	Loy & Dixon	Various sites, Eastern Beringia	36	200-1000x	N	Am Ant	No dates provided. Observed blood film, red blood cells on Beringian fluted points. Immunological and DNA tests confirmed mammalian blood, including mammoth.
1998	Piperno & Holst	Central Panama, 1.3-7ka	13	100-1000x	N	JAS	Observed manioc, maize, arrowroot, and legume starches, as well as Zea sp. and palm phytoliths.
1998	Wallis & O'Connor	Widgingarri Shelters 1 and 2, WA, Australia, <4970BP	42	-	-	-	In <i>A Closer Look</i> . Examined stone points for residues. No magnification information provided. Worked material assessed as plant/animal.
1997	Fullagar & David	Ngarrabullgan Cave, Qld, Australia, 930-5400BP and 32.5->37.2ka	257	25-1000x	Y	CAJ	Found hair, blood, starch, feather, collagen; results are presented as plant/animal. Discusses implications for social perceptions of the site.
1997	Fullagar & Field	Cuddie Springs, NSW, Australia, modern-33ka	33	Up to 1000x	Y	Antiquity	Found distinctive phytoliths, generally small starches and blood films on grinding stones. Contact material presented as plant/animal.
1997	Veth, Fullagar <i>et al.</i>	Puntutjarpa Rockshelter, WA, Australia, 435-10,170BP	2	-	Y	AA	No information reported on methods or magnification. Starch was observed on two grindstone fragments.
1997	Williamson	Rose Cottage Cave, South Africa, 9.5-13.5ka	30	-	Y	SAJS	Follows from and combined with data reported in Williamson (1996); reports plant/animal processing and DNA extraction (not sequencing)

Year	Author(s)	Site, age (approx.)	# ¹	Mag. ²	U-w ³	Journal ⁴	Summary
1996	Sobolik	Hinds Cave, Texas, USA, 2-5ka	55	10-400x	Y	JFA	Residues observed at 10-15x in situ, then removed with a wooden scraper and examined at up to 400x.
1996	Williamson	Rose Cottage Cave, South Africa, 6ka	167	50-500x	Y	SAFA	Reports plant/animal processing, with a predominance of plant. Fungal residues were found on one third of artefacts, and non-formal tools had residues.
1995	Tuross & Dillehay	Monte Verde, Chile, 12.5-13.2+ka	7	4-20x	N	JFA	Residues screened via microscopy, but analyses conducted using immunology – no correlation between observed 'stains' and immunological results
1994	Loy	Mustang Branch and Barton sites, Texas, USA	108	100-1000x	Y	-	In <i>Human Ecology in the Middle Onion Creek Valley</i> . Results reported as plant/animal, with additional chemical tests (also examined 40 burned rocks).
1993	Barton & White	Balof 2, New Ireland, Papua New Guinea, <14ka	21	>100x	Y	AP	Identified tuber processing on most artefacts over the 14,000 year period. Animal residues were not present.
1993	Boot	Graman, NSW, Australia, 2-5.5ka	2722	24-1000x	Y	-	In <i>Archaeometry: Current Australasian research</i> . Initial low-magnification screening showed 720 artefacts with evidence of use, 165 had use or hafting residues.
1993	Fullagar	West New Britain, Papua New Guinea, >3.5ka	43	-	Y	-	In <i>Traces et Fonction</i> . Identified starch grains, phytoliths and blood. Discusses plant vs animal processing, change over time, and phytoliths in particular. No magnifications provided.
1993	Fullagar	West New Britain, Papua New Guinea, >3.5-4ka	1	10-500x	Y	-	In <i>Archaeometry: Current Australasian research</i> . Recovered phytoliths from adhering soil, and observed in situ phytoliths, starch, raphides, fungal remains and suspected blood.
1993	Furby, Fullagar <i>et al.</i>	Cuddie Springs, NSW, Australia, 19-28ka	-	-	Y	-	In <i>Sahul in Review</i> . Few specific details of the study provided. Red blood cells, animal tissue, mammalian hair and woodworking/plant processing residues identified on flaked stone. Starch found on a grindstone.
1993	Loy	Toad River Canyon, Canada, 2200BP	11	-	N	WA	Identified blood/hair/animal tissue, as well as some plant remains. Immunological and DNA tests were then employed.

Year	Author(s)	Site, age (approx.)	# ¹	Mag. ²	U-w ³	Journal ⁴	Summary
1992	Fullagar	FEA, West New Britain, Papua New Guinea, recent-3500BP FRL, West New Britain, Papua New Guinea, recent->3500BP FRI, West New Britain, Papua New Guinea, recent-3500BP FOF, West New Britain, Papua New Guinea, 2000->3500BP FHC, West New Britain, Papua New Guinea, recent->3500BP FGT, West New Britain, Papua New Guinea, recent->3500BP	55 420 63 31 302 85	6-500x	Y	-	In <i>Poterie Lapita et Peuplement</i> . Studied obsidian flakes from six sites, divided into three phases based on Lapita occupation. Results presented as plant vs animal processing, with discussion of changes in resource exploitation and site specialisation.
1992	Fullagar, Meehan <i>et al.</i>	Various sites, Northern Australia, <2ka	72	<300x	Y	-	In <i>Prehistoire de l'Agriculture</i> . Examined a variety of ethnographic and recent archaeological artefact materials (72 of which were archaeological stone). Plant and animal identifications.
1992	Hurcombe	Ortu Comidu, Sardinia, 2-3.5ka	12	250-625x	Y	-	In <i>Use-wear Analysis and Obsidian</i> . Residue morphology is described, rather than assigned to particular origins; possible plant.
1992	Loy & Hardy	Tabun Cave, Israel, 90ka	10	12-1000x	N	Antiquity	Microscopic and immunological study of blood residues. Concludes tools used for (unspecified) animal processing.
1992	Loy, Spriggs <i>et al.</i>	Kilu Cave, Solomon Is., <9ka & 20-28.7ka	47	500-1000x	Y	Antiquity	Identified taro (<i>Colocasia esculenta</i> and <i>Alocasia macrorrhiza</i>) starch grains and raphides.
1992	Sievert	Chichen Itza, Mexico	166	50-200x	Y	-	In <i>Maya Ceremonial Specialization</i> . No specific dates available, although likely >500BP. Identified resins, gold, pigment, plant tissue, possible blood on artefacts that had previously been chemically cleaned. See also Sievert (1990, 1992b).
1991	Loy	Unspecified Moa butchery sites, New Zealand, 1000BP	20	-	-	-	In <i>Archaeometry '90</i> . Very little information – no data on techniques or sites. Identified moa feather fragments on 5 tools.

Year	Author(s)	Site, age (approx.)	# ¹	Mag. ²	U-w ³	Journal ⁴	Summary
1990	Hyland, Tersak <i>et al.</i>	Shoop, Illinois, USA, 8ka	45	<10x	N	Am. Ant.	Very low magnification initial screening of artefacts for subsequent Hemastix and immunological testing for blood. One artefact possessed blood (cervid) residue.
1990	Jones	Kutikina Cave, Tasmania, Australia, 15-17ka	-	-	Y	-	In <i>The World at 18,000BP</i> . Few details provided (no magnifications, number of tools). Found evidence of meat, bone, plant and wood working.
1990	Loy	Lake Mungo, NSW, Australia, 20-35ka.	-	-	Y	ANH	No details of methods and number of tools examined are provided. Identified starch grains and plant tissue, blood, sinew and periosteum.
1989	Fullagar	Ritamauda rockshelter (QBB), Papua New Guinea, 0-3500BP	161	6-400x	Y	-	In <i>A Crack in the Spine</i> . Found organic smears and fragments, fibres, plant tissue, silica particles. Palm, reed and wood working inferred.
1989	Hall, Higgins <i>et al.</i>	SE Queensland, Australia	10	6-400x	Y	-	In <i>Plants in Australian Archaeology</i> . No dates provided. Found starches and plant tissue on pounding tools (and slides made from the tools).
1989	Loy & Wood	Cayonu Tepesi, Turkey, 6.8-7.4ka	398	-	N	JFA	No details of magnification. Artefacts were screened microscopically in the field for blood, then residues removed for lab testing. Identified human, auroch and <i>Ovis</i> sp. blood.
1989	Newman & Julig	Cummins site, Thunder Bay, Canada, 7.5-9ka	36	10-40x	N	CJA	Artefacts initially screened using low-power microscopy. Potential blood residues identified, then tested immunologically.
1989	Richards	Thorpe Common rockshelter, Yorkshire, UK, 5.7-6.4ka	50	10-625x	N	-	In <i>Breaking the Stony Silence</i> . Blood residues identified on 41 tools through microscopy and chemstrip testing. Observed blood also in the soil matrix immediately adhering to some artefacts.
1988	Fullagar	Aire Shelter II, Victoria, Australia, <600BP	1814	-	Y	-	In <i>Industries Lithique</i> . Study reported briefly, no magnifications provided. Residues on 13 tools, including collagen.
1987	Fullagar	Birrigai rockshelter, ACT, Australia, <1000-21000BP	69	-	Y	AO	Identified residues on 9 of the 69 artefacts. Found blood, collagen, plant and possible ochre. Blood may not be from tool-use. No magnifications provided.
1987	Jones	Kutikina Cave, Tasmania, Australia, 17-20ka	1	300x	Y	AG	No information on number of artefacts analysed (only the results from one are reported). Found collagen and blood identified as red-necked wallaby.

Year	Author(s)	Site, age (approx.)	# ¹	Mag. ²	U-w ³	Journal ⁴	Summary
1987	Loy	Barda Balka, Iraq, 75-125ka; Jarmo, Iran, 8-10ka; Unspecified site, Belgium, 20ka	3 5 2	-	-	-	In <i>Archaeometry: Further Australasian Studies</i> . Three studies mentioned very briefly – little detail on methods or results. Found blood cells and mammalian blood deposits.
1985	Frederickson	Whakamoenga Cave, New Zealand; Twilight Beach, New Zealand	138 61	15-50x	N	NZAAN	No dates provided. Examined obsidian flakes from two sites for blood residues via light microscopy, test-strips and SEM. Light microscopy identified fibrous material, and deposits of various colours. Subsequent SEM identified erythrocytes.
1985	Loy	Hidden Cave, Nevada, USA	1	5-800x	N	-	In <i>The Archaeology of Hidden Cave</i> . No dates provided. Identified bat hair and presumed bat blood, as well as feather barbules.
1984	McBryde	Graman, NSW, Australia, 1-5ka	-	-	Y	-	In <i>Recent Advances in Indo-Pacific Prehistory</i> . No data on magnifications provided. It is unclear how many artefacts were examined (possibly 900). Identified hafting 'stains' on 26 backed blades from 3 sites.
1983	Loy	Various sites, Canada, 1-6ka	104	12-500x	-	Science	Blood residues observed on 90 artefacts, as identified by a variety of tests; species identified via haemoglobin crystallisation.
1982	Coughin & Claassen	Vail, Maine, USA, Palaeo-Indian	27	160x	N	-	In <i>The Vail Site</i> . Initial in situ observation of 'tiny biological fragments', followed by removal to slides. Observed well-preserved phytoliths, and plant tissue.
1979	Shafer & Holloway	Hinds Cave, Texas, USA, 2-5ka	25	10-400x	Y	-	In <i>Lithic Use-wear Analysis</i> . Initial observation of plant fibres and epidermis in situ, then removal to slides (for 11 tools). Found phytoliths, hairs, starch, and more, some identifiable to species
1976	Briuer	Chevelon Canyon and Cayote Creek Pueblo, Arizona, USA, 700-8700BP	2551	30x	Y	Am Ant	Used low-magnification to screen artefacts, found 37 with 'organic use residues'. These were classified (using chemical tests and morphological inspection) as plant or animal.

1: # = the number of artefacts examined. This number is often much larger than the number of artefacts with residues.

2: Mag. = magnifications used by the analyst.

3: U-w = whether or not use-wear was also examined in the study [Y = yes; N = no; - = insufficient information].

4: Journal = the journal in which the study was published. See below for abbreviations. If the study was not published in a journal, the source is listed in the 'Summary' column.

Journal abbreviations:

AA	Australian Archaeology	LAA	Latin American Antiquity
AAS	Australian Aboriginal Studies	NS	New Scientist
AG	Australian Geographic	NZAAN	New Zealand Archaeological Association Newsletter
Am Ant	American Antiquity	NZJA	New Zealand Journal of Archaeology
ANH	Australian Natural History	PNAS	Proceedings of the National Academy of Sciences
AO	Archaeology in Oceania	RAM	Records of the Australian Museum
AP	Asian Perspectives	RPP	Review of Palaeobotany and Palynology
CAJ	Cambridge Archaeological Journal	SAAB	South African Archaeological Bulletin
CJA	Canadian Journal of Archaeology	SAFA	South African Field Archaeology
HA	Hawaiian Archaeology	SAH	Southern African Humanities
JAS	Journal of Archaeological Science	SAJS	South African Journal of Science
JFA	Journal of Field Archaeology	VHA	Vegetation History and Archaeobotany
JHE	Journal of Human Evolution	WA	World Archaeology
JNAS	Journal of Nordic Archaeological Science		