SAND TRAPS FOR THE UNWARY - PROBLEMS IN THE INTERPRETATION OF SEDIMENTOLOGICAL ANALYSES

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Abstract The principles of sedimentology are briefly described. Four recently published archaeological reports containing sedimentological analyses are critically reviewed and it is suggested that they could all have been improved if the archaeologists who undertook them had discussed their investigations with a sedimentologist before beginning laboratory work-. Finally, reference is made for comparative purposes to some sedimentological work recently undertaken in Western Australia and a plea is entered that archaeologists familiarise themselves with the full range of sedimentological techniques before undertaking their own analyses.

Introduction

A voluminous literature exists on the interpretation of the sedimentary matrix in archaeological sites (e.g. Schmid 1958; Rosenfeld 1964; Farrand 1975, 1979; Tankard and Schweitzer 1976; Webb 1980; Butzer 1981; Stein and Farrand 1985), which is being continually added to, particularly in the pages of the journal *Geoarchaeology*. This literature is not confined to European and North American studies; some excellent work has also been done in Australia (Frank 1971; Shackley 1978; Hughes 1980). However, this literature seems to have been ignored by some Australian archaeologists with the result that their sedimentological analyses do not bear detailed scrutiny. For example, reports have recently been published on excavations undertaken at four rockshelters in Queensland as part of postgraduate research (David 1990; Beaton 1991a, 1991b). While the publication of the data these sites contained is warmly welcomed, the sedimentological analyses described in all these reports raise questions of methodology and interpretation.

First, a few words of explanation. In order to determine the origin and means of deposition of a sediment it is necessary to study both its physical characteristics, the range of particle sizes it contains, their degree of angularity or roundness and their colour, and its chemical characteristics, particularly its relative acidity (pH), and, in the case of sediment from archaeological sites, the proportion of organic remains and, where relevant, the secondarily deposited $CaCO_3$ it contains.

It is the characterisation of the sediment via particle size analysis which seems to cause the greatest problem for archaeologists. They appear to think that sieving the sand fraction is all that is required. However, 'sand' is only one of a range of particle sizes into which most sediments can ordinarily be subdivided (Gale and Hoare 1991:58-9). The most commonly occurring range of potential size classes is shown in Figure 1, together with the points on the phi (ϕ) scale which demarcate the different clast size categories. This system, and the sedimentological categories shown on the triangular textural diagram, have international validity.

Although in Figure 1 the phi scale is shown as graduated from -6ϕ (coarser) to 10ϕ (finer), like the Richter scale, it is theoretically open-ended. Moreover, although there is some dispute as to where the silt/clay

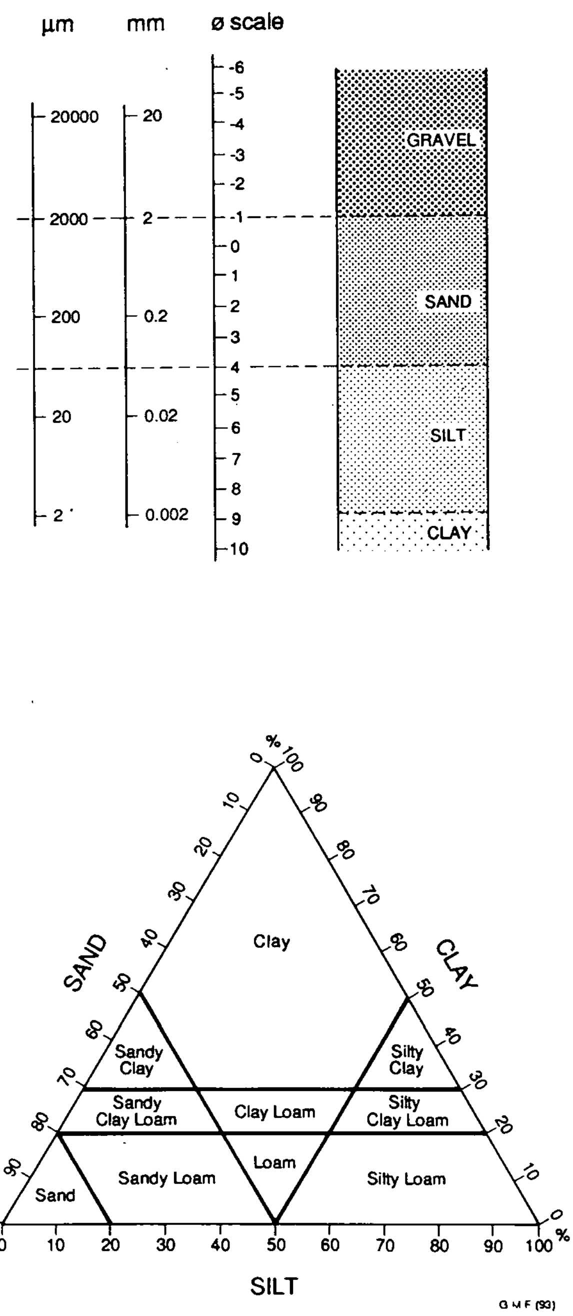

Figure 1: Textural, clast and sieve size classifications (after Vita-Finzi 1978: Figure 47)

boundary falls, largely because these particle sizes are so difficult to measure, the parameters of the sand fraction are not open to question. 'Sand' is that fraction of a sediment whose particles fall between -1ϕ and 4ϕ in size. It is usually measured by shaking a known weight of sediment, from which the silt and clay fractions have been removed by washing, through a series of graduated Endecott sieves for a stated time and weighing the amount of sediment resting on each sieve (Gale and Hoare 1991:31-7). In rockshelter deposits, the gravel fraction is frequently not subdivided because the quantities of sediment needed to obtain an adequate sample of each clast size are prohibitively large (Farrand 1975, 1979). However, unless the proportion of silt and clay in a sediment has been calculated the deposit from which they came has not been fully characterised and its origin and mode of deposition may remain obscure. These fractions can only be calculated by invoking Stokes' Law, which states that particles in suspension will settle out at a rate dependent upon their size, shape and density. The rate of settling is determined on an aliquot of sediment <4ϕ in an aqueous suspension (Gale and Hoare 1991:87-94). It is assumed in sedimentation tests that silt and clay particles are spheres with the mass of quartz, a specific gravity of 2.7, and that smaller particles settle more slowly because they are lighter, while larger particles settle more quickly because they are heavier. However, that is not always true. All forms of sedimentation test are time-consuming, because of the slow rate at which clay particles settle out of suspension, and subject to error, because some particles, for example mica, are much larger and lighter than quartz and hence settle out too slowly (Webb 1980), and some particles, for example clays derived from Fe-rich rocks, are much denser and settle out too fast. However, these problems are known and will be allowed for by an experienced sedimentologist in the interpretation of the results of particle size analysis.

With these observations in mind, I wish to reconsider the sedimentological analyses reported by David (1990) for Echidna's Rest rockshelter and by Beaton (1991a, 1991b) for Rainbow, Wanderer's and Cathedral caves.

Echidna's Rest

In this report, David (1990:75) described the sedimentary matrix in Square 12 as a 'fine ashey' (sic) deposit. Subsequently, he commented that the organic content of the matrix could not be calculated using the weight-loss-on-ignition technique (Gale and Hoare 1991:262-4) because of the high clay content of the matrix. However, he does not appear to have actually calculated the clay fraction! His Figure 4 (David 1990:77, reproduced here as Figure 2) shows only the results of sieving the sand fraction of the matrix. David appears to have used an idiosyncratic range of sieve sizes with which the fine sands were unnecessarily subdivided. I cannot help but wonder whether the unusual range of sieves David employed actually represented all that were to hand at ANU at the time. If so, he would have been better advised to have employed only whole-phi intervals, since they demarcate the boundaries between the various sand fractions (Gale and Hoare 1991:58-9). Any textbook on sedimentary petrology (e.g. Krumbein and Pettijohn 1938) would have yielded similar information to that found in Gale and Hoare, which as the most recent publication on the analysis of Quaternary sediments would not have been available to David.

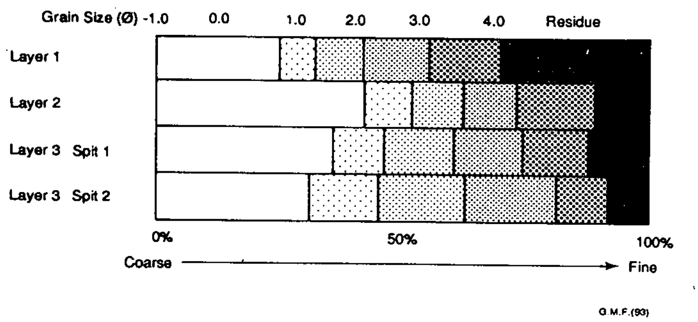

Figure 2: Analysis of the sand fraction from Echidna's Rest rockshelter (after David 1990: Figure 4)

In order to interpret the sand fraction sensibly it would be desirable to know the full characteristics of the sedimentary matrix, that is the size of the gravel, silt and clay fractions; although the 'particle size distribution alone is usually inadequate as a means of deter-mining the environment of deposition of a sediment' (Gale and Hoare 1991:74). I would like to know why David did not calculate these fractions.

On archaeological sites, it is rarely necessary to characterise the sedimentary matrix fully. This involves the labour of pipette analysis (Webb 1980; Gale and Hoare 1991:87-94). Quick, simple and reasonably accurate methods exist (Krumbein and Pettijohn 1938:172-6; Webb n.d.) by which the proportions of sand:silt:clay can be determined, once the gravel fraction has been removed. I would suggest that sedimentary matrices should always be fully characterised to facilitate their interpretation.

As it is, all that can be said about David's Figure 4 is that the sand fraction comprises mainly coarse to very coarse particles and that overall its seems to represent a fining-upwards sequence (although the proportion of very coarse particles also increases upwards). These clasts were presumably derived from the parent bedrock, although David did not discuss the origin or means of deposition of any of the sedimentary matrix. There is clearly a major change between the depositional environments of Layers 1 and 2. The silt and clay fraction represents about 30% of Layer 1, whereas in Layers 2-3 it has declined to <15%, while the very coarse sand fraction has increased to 45%. The explanation offered by David (1990:77), that the preponderance of fine sediment in Layer 1 is due to 'the presence of a relatively large amount of ash and $CaCO_3$' is as good as any other in the absence of a full particle size analysis.

Rainbow, Wanderer's and Cathedral Caves

As with David's (1990) more recent work at Echidna's Rest, the sedimentological analyses Beaton (1991a, 1991b) undertook as part of his doctoral research raise questions of methodology and interpretation. David (1990) at least analysed the sand fraction in his sedimentary matrix, however Beaton analysed particles in the size range -2ϕ to +2ϕ. That is: the smallest gravel size class and the very coarse to medium sand fraction (Figure 1). I confess to complete bewilderment. Why stop half-way when sieving sand? Can it be that back in the mid-70s the ANU did not have any 3ϕ or 4ϕ sieves? The latter are as notoriously subject to damage as Endecott sieves are horrifyingly expensive. However, in this case, a job half-done was possibly not worth doing at all, because the particle sizes Beaton investigated make no depositional sense and yielded very little information.

As with Echidna's Rest, Beaton's results would have been far more informative if he had characterised the whole sedimentary matrix. It would have been particularly useful to know the full parameters of the sand fraction because these shelters have all developed in sandstone of Triassic age, weathered particles from which could reasonably be expected to have furnished the sand fraction in their sedimentary matrices. As it is, Beaton (1991a, 1991b) did not attempt to explain the origin or means of deposition of any of these sedimentary sequences.

However, Beaton does appear to have performed miracles. The flow diagram (Beaton 1991a:Figure 4, reproduced here as Figure 3) illustrating the successive stages through which each sediment sample passed suggests that the sediment <2ϕ was rebagged and stored for future research. I would like to know how Beaton achieved this feat. Although particles <2ϕ will obviously pass through a 2ϕ sieve, that is the whole purpose of sieve analysis, ordinarily water has to be used to clean the sand grains of clay particles, which are very adherent. Beaton *cannot* have wet sieved his samples if they were rebagged. Hence, the sand fraction was almost certainly *not* clean, by definition. In that case, the weights of the different sand fractions will be incorrect.

Beaton's failure to characterise fully the sedimentary matrix at these shelters is particularly to be regretted because so much information has probably been lost beyond recall.

For example, at Rainbow Cave Beaton's Figure 5 (1991a:15, reproduced here as Figure 4) shows that 50-75% of the total sediment matrix passed through the 2ϕ sieve. In other words, Beaton only characterised 25-50% of the sediment at this shelter. The sediment fraction that he did analyse shows little change throughout the depositional sequence.

At Wanderer's Cave, on the other hand, Beaton (1991a:27) claimed that 'the distribution of the particle size does not differ significantly between levels within the deposit, nor is the total picture of a different character than that of the Rainbow Cave deposit'. Based on Beaten's Figure 10 (1991a:30, reproduced here as Figure

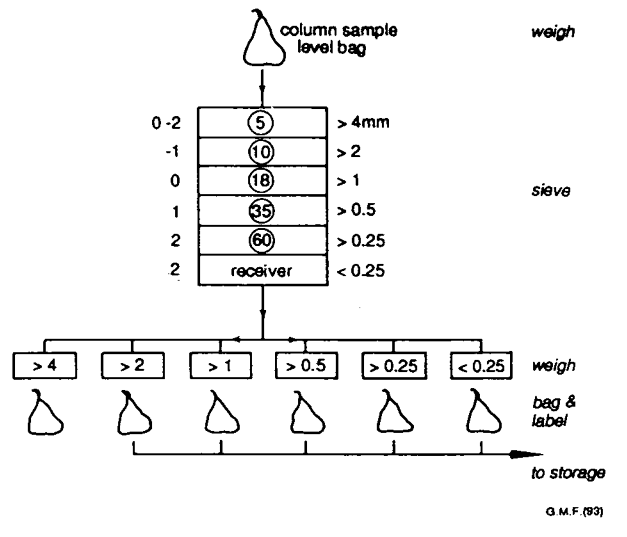

Figure 3: Flow diagram of column sample analysis (after Beaton 1991a: Figure 4)

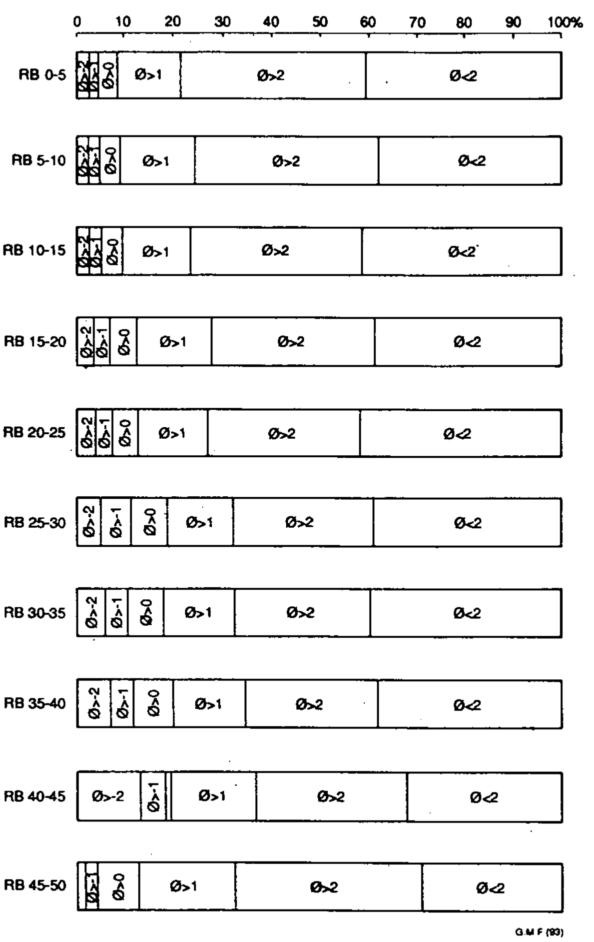

Figure 4: Particle size distibutrion at Rainbow Cave (after Beaton 1991a: Figure 5)

5), that interpretation is incorrect. This figure shows that about 20% of the sedimentary matrix in the basal spit was <2ϕ, while medium sand predominated. In the three superjacent spits the <2ϕ fraction declined to <15%, while gravel predominated. Only the five uppermost spits produced profiles similar to those at Rainbow Cave. In each case 30-40% of the sediment sample passed through the 2ϕ sieve and was not analysed. One explanation for this marked change in the sedimentary profile may lie in the relative acidity (pH) of the deposits (Beaton 1991a: Figure 9, reproduced here as Figure 6). The pH values above a depth of -250mm, in the middle of layer 4, suddenly rise from <5.0 to 7.0. This suggests that the basal sediments were deposited under a different environmental regime from the upper layers. This interpretation differs considerably from that offered by Beaton (1991a:27-30).

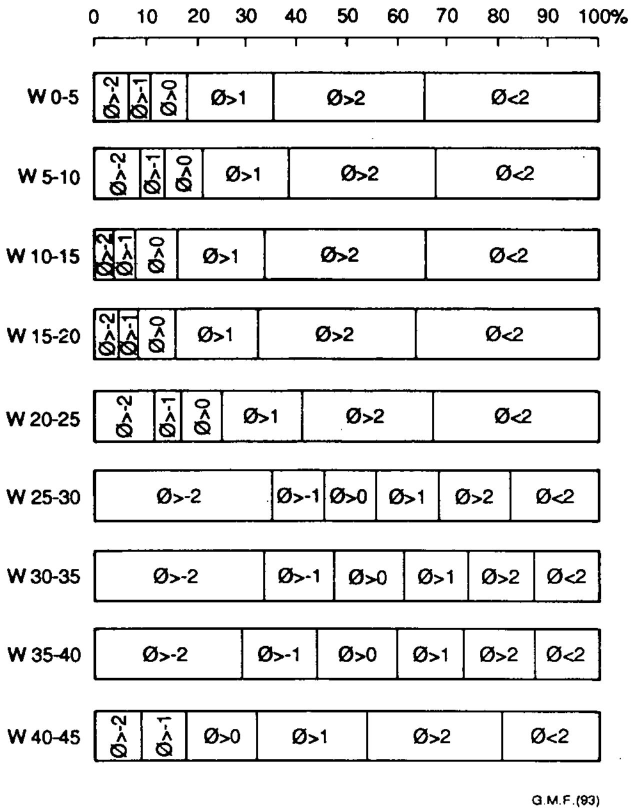

Figure 5: Particle size distribution at Wanderer's Cave (after Beaton 1991a: Figure 10)

Finally, at Cathedral Cave the loss of information entailed by Beaton's failure to investigate the sediment matrix <2ϕ became overwhelming. Beaton (1991b:47-50) identified 11 excavational levels at this shelter, each approximately 150mm deep, although he analysed a total of 15 sediment samples. In all of them >50% of the total sediment matrix passed through the 2ϕ sieve (Beaton 1991b:Figure 6, reproduced here as Figure 7). Indeed in nine of the 15 samples he analysed, 80% of the matrix passed through the 2ϕ sieve. In other words, for 60% of the sediment samples Beaton analysed from this shelter he only characterised 20% of the matrix. For the remaining six samples he analysed <50% of the matrix. Hence, it is not surprising that his analyses are difficult to interpret.

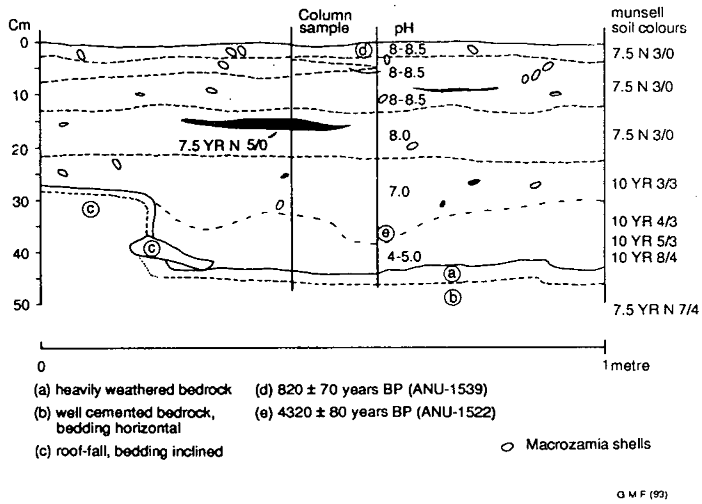

Figure 6: Stratigraphic section at Wanderer's Cave (after Beaton 1991a: Figure 9)

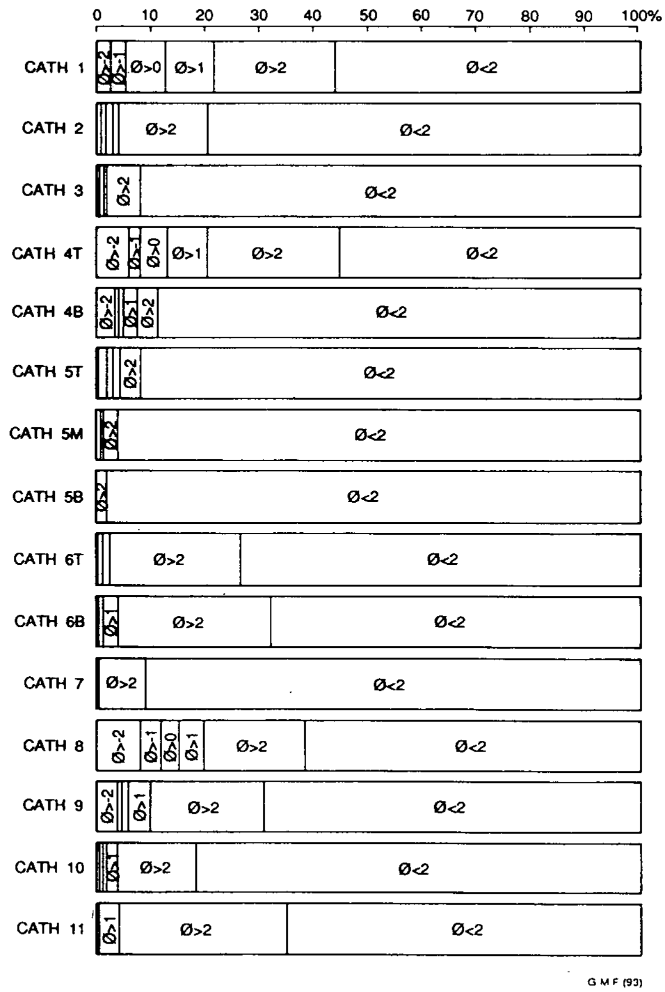

Figure 7: Particle size distribution at Cathedral Cave (after Beaton 1991b: Figure 6)

Beaton (1991b:49) claimed that the occupation levels at this shelter contained a greater percentage of larger clasts than did the sterile layers. Unfortunately, based on the analyses he performed this statement is untestable.

He further claimed (1991b:49) that if he had analysed the silt and clay fractions he would have skewed the description of those sterile strata towards their fine component. That claim is mistaken. Only if Beaton had characterised the <2ϕ fraction for all the samples he analysed would he have known what proportion of silt and clay they contained. That knowledge could in no way have skewed the description of the matrix. It would merely have defined the silt and clay fractions.

A more interesting question to answer would have been why is the sedimentary profile of the sterile deposits at the base of layer 4 and in layer 5 was so fine-grained when >40% of the sterile sediments lower down the stratigraphic profile comprised particles coarser than 2ϕ. Beaton did not even consider that problem.

Discussion

The remarks made above are meant as *constructive* criticisms. My intention is not to denigrate Beaton's or David's work. It has the outstanding merit that they have both published their analyses and results in forms which can be at least partially reinterpreted by anyone interested to do so. Moreover, they are certainly not alone in having studied only a portion of the total particle distribution in the sedimentary matrices at their sites, but the other examples of which I am aware are contained in unpublished theses and hence unavailable for comment. However, their work would have been greatly improved if they had discussed with a sedimentologist what questions their analyses were intended to answer before they began their laboratory work. The interpretation of - sediments is as highly specialised a field of knowledge as is the interpretation of lithic artefacts. It is most usefully undertaken with the guidance of an expert.

Beaton's and David's work does show that some aspects of sediment analysis need to be emphasised for archaeological practitioners. Otherwise, mistakes can occur. The sedimentary matrix found on archaeological sites comprises the *totality* of all the particle sizes available, from the largest to the smallest. Hence, the entire spectrum of particle sizes available at any given site *must* be considered before any attempt can be made to determine their origins and mode of deposition. This is particularly true for rockshelters, which tend to display a markedly bimodal particle size distribution, comprising an angular gravel fraction, produced by mechanical fracturing and chemical dissolution of the roof and walls of the shelter and a much finer matrix which normally comprises fine sands, silts and clays. This fine fraction is brought into the shelter by a variety of means: treadage by humans and other animals, as dust in fur or on clothing, by wind action, etc. If the parent material in which the rockshelter has tonned disintegrates easily, then its constituent particles will be well-represented in the matrix. These clasts can be derived by chemical disaggregation either directly from the rockshelter walls or from the disintegration of larger clasts of the parent rock after they have become incorporated in the sedimentary matrix. It is therefore essential to consider the topographic location in which a rockshelter has formed and the lithology of the country rock before any attempt is made to interpret the sedimentary matrix found during excavation.

For example, in my forthcoming doctoral dissertation (Webb n.d.) I analysed sediment samples from rockshelters which have formed in deeply weathered granitic rocks of Archaean age, beneath capping lateritic deposits which tonned during the Tertiary. The particle size, distributions of the sediment matrices in these shelters are not only congruent, as could be expected given that the shelters have all developed in the same country rock, but also markedly bimodal (Figure 8). Each sample contained a variable weight of angular gravel-sized clasts derived from the shelter walls and roof, while the fine fraction comprised a sandy-silt (Figure 9). I presume that most of the sand fraction has derived either from the laterite or represents the quartz grain residue from decomposed granite, while the silt and clay fractions derive from the kaolinised granites of the pallid zone (de la Hunty 1975; Watkins 1990).

I have recently analysed some sediment samples from a rockshelter which has formed in fine-grained metamorphosed Fe-rich rocks of Proterozoic age (Webb, unpublished data). The deposits appear to comprise two units: a sandy-silty mildly acidic upper unit of Holocene age, and a markedly acidic silty lower unit, which is probably Pleistocene in age. When prepared for hydrometer analysis the samples from the lower unit behaved unusually. Long before the clay particles would ordinarily have settled out, the suspension had cleared. Hence, the lower unit appeared to contain little clay. However, that is not necessarily the correct interpretation. I believe that the clay-sized particles in the lower unit settled out unusually rapidly due to their high specific gravity. They are the weathered residue of the Fe-rich country rock and thus extremely dense. Their mass does not conform with Stokes'Law. Unfortunately, no method for analysing the size of particles <4ϕ exists which avoids the problem of particles with specific gravities >2.7 or <2.7. Cases such as I have just described require a knowledge of the local geology to facilitate interpretation.

The oldest basal date I obtained from the deposits in the Murchison shelters I investigated was about 3500 BP. Hence, those sedimentary sequences formed after the present climatic regime was well established. However, the lower unit in the unpublished shelter probably formed when the climate of the region was markedly colder and more than it is at present, according to Bowler's (1976, 1982, 1986) climatic reconstructions. Those climatic differences may well have influenced the Fe-rich nature of the lower unit in that shelter.

Conclusions

To a sedimentologist, it is as meaningless to discuss just the sand fraction of a deposit as it is to a lithic analyst to describe a flaking technology from the Kimberley as 'Levallois' (Bordes 1976). In the first case, the sedimentologist's response will be: what about the rest of

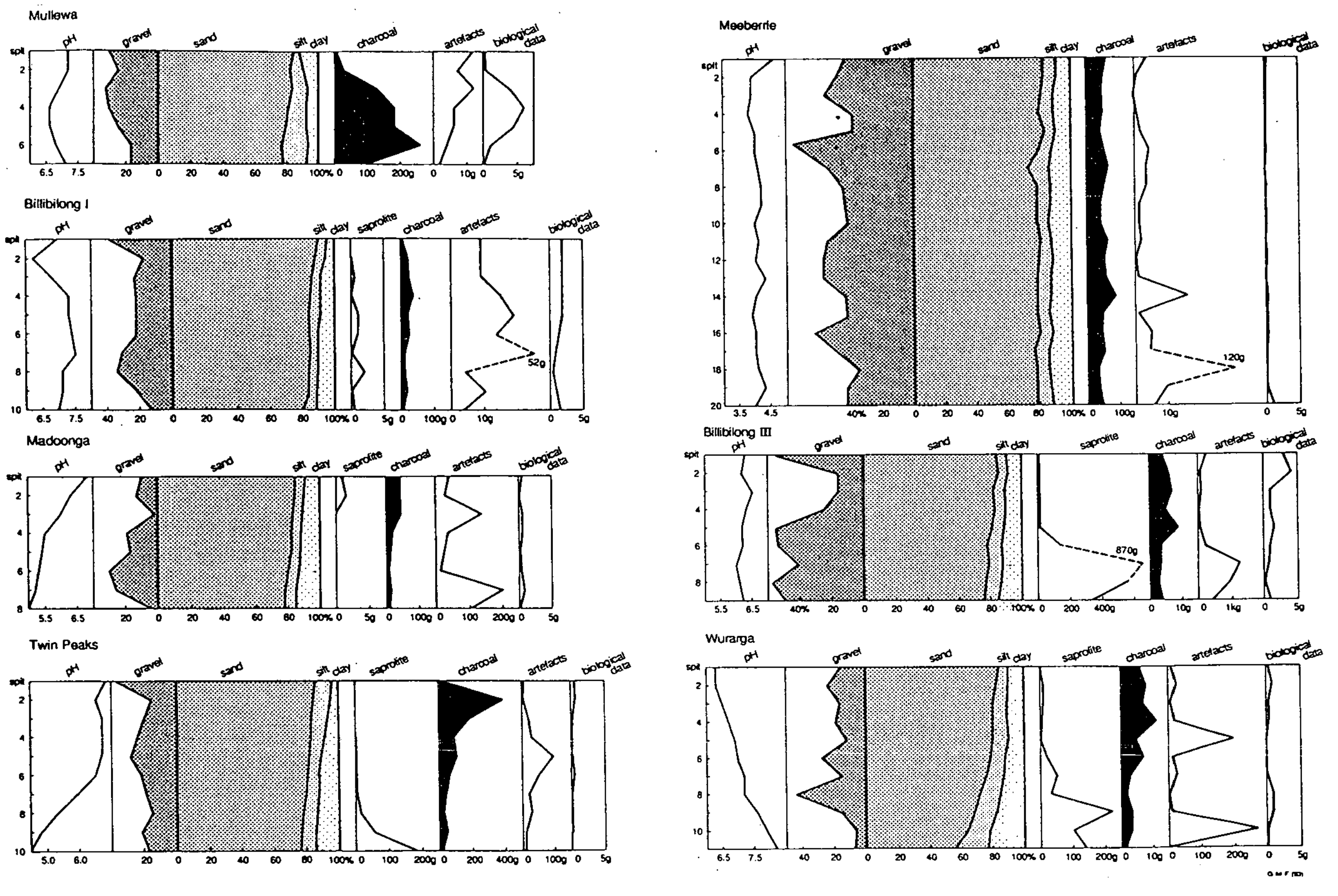

Figure 8: Particle size distributions at Murchison rockshelters (Webb n.d.)

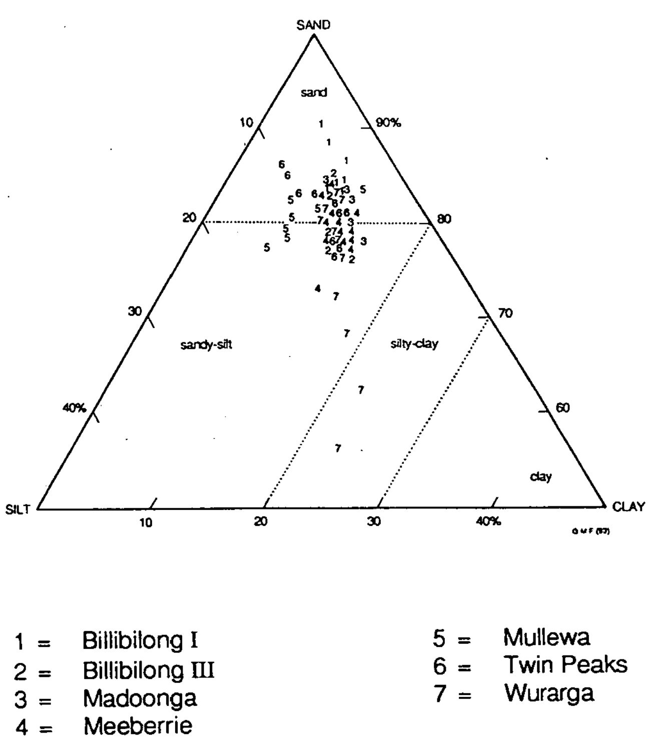

Figure 9: Triangular textural diagram of the data shown in Figure 8 (Webb n.d.)

the sediment? In the second case, a kind-hearted lithic analyst will think: clearly Bordes considered the cores at this site had been 'prepared' prior to flaking, but calling the technique 'Levallois' implies unlikely and unhelpful cultural parallels.

The purpose of these comments has not been simply to criticise either Beaton's or David's work, but rather to persuade Australian archaeologists in general of the importance of three points. First, the interpretation of sedimentary sequences is an art on which there is a vast literature, mainly published in the *Journal of Sedimentary Petrology and Geoarchaeology*. Second, they should recognise that sieving the sand fraction is only part of the analysis of the sedimentary matrix at most archaeological sites. Only when archaeological sites are located in sand dunes can one afford to analyse solely the sand fraction of the matrix. However, in that case, it should probably fully characterised, down to quarter-phi intervals. Third, archaeologists who wish to interpret the environment(s) under which the sedimentary sequence was deposited at the site they have just excavated should always consult a sedimentologist before beginning their laboratory analyses. They may save themselves a lot of unnecessary labour.

Acknowledgments

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