Element Concentrations and Magnetic Susceptibility of Anthrosols: Indicators of Prehistoric Human Occupation in the inland Pilbara, Western Australia

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Abstract
The study of archaeological sediments is an important source of information on how humans lived at a site. Attributes of human site use such as frequency of visit and duration of stay can be explored by measuring changes in phosphorus (determined using X-Ray Fluorescence) and carbon concentrations in sediments and magnetic susceptibility of sediments in combination with analysis of other sediment attributes, stone artefacts and faunal remains. This study concludes that increases in phosphorus and carbon concentrations and the discard rate of stone artefacts at Marillana A rockshelter in the inland Pilbara, Western Australia, indicate an increase in the frequency of site use with no change in the function of the site. This is interpreted as representative of an increase in regional population density.

Keywords
Element concentrations, Phosphorus, XRF, Magnetic susceptibility, Pilbara, Australian Aboriginal Archaeology

Introduction

Recent studies indicate that analysis of physical and chemical properties of archaeological sediments can contribute towards an understanding of human occupation when lithic or ceramic artefacts are sparse [26, 32, 36, 45]. This paper presents the results of the use of X-Ray Fluorescence (XRF) of archaeological sediments in combination with other techniques to investigate changes in occupation magnitude at a stratified site with a relatively low density of stone artefacts. The low density of stone artefacts at this site means that the analysis of artefacts has limited power in distinguishing between different explanations for changes in the rate of artefact discard. Other techniques used here include the analysis of carbon concentrations in the sediments, magnetic susceptibility of the sediments, pH and soluble salt concentrations of the sediments. The site, Marillana A (figure 1), has evidence of prehistoric human occupation dating to before 13,000 BP. Results of these combined analyses suggest that between 9,000 BP and 3,000 BP there was an increase in the frequency of visits to the shelter. This increase in visits is best explained by an increase in population density in the region because there is no evidence of a shift in land-use or technological strategies.

Insert figure 1 about here: "Figure 1. Map of inland Pilbara showing the location of Marillana A"

The problem at Marillana A

Although over fifty archaeological sites have been excavated in the inland Pilbara, the paucity of cultural remains recovered from each site makes it difficult to produce convincing descriptions of cultural and economic change over space and time [30]. The small number of artefacts at each site may be the result of a series of brief, single events rather than be representative of the longer term trends relevant to understanding regional sequences. This is a common pattern in semi-arid inland areas where large sites with dense, deep sequences do not occur. In this context, Marillana A is an important site because it has a typically small stone artefact assemblage, a relatively long sequence of human occupation and archaeological sediment samples available for analysis. The chemical and physical attributes of the sediments provides additional strands of evidence to discern between changes in site function and intensity of site use.

Marillana A is a south-facing rockshelter in the Marra Mamba ironstone formation at the top of a short steep-sided gully that runs off Marillana Creek. The shelter is 22.5 m wide and 6.5 m high at the drip line and 5.5 m deep. Large boulders of roof-fall occur across the front of the shelter, 2.5 m beyond the drip line. These boulders have prevented sediments from moving out of the rockshelter, resulting in a large, dry and level surface suitable for human occupation. Lynda Strawbridge excavated two one metre by one metre squares to a depth of 1.5 metres at Marillana A in 1991 and 1993. In 1991 a one by one metre square (labelled 11B) was excavated in 16 units of about six centimetres each to a depth of 99 cm. The square was located just behind the drip line at a point where the depth of the shelter was greatest. In 1993 a second one by one metre square (labelled 9B) was excavated in 53 units of about three centimetres each to a depth of 147 cm. Bulk samples of sediment were collected from each excavation unit during the excavation. The excavation was part of a cultural heritage salvage project preceding a mineral exploration program undertaken by the natural resources company BHP.

Archaeological material from Marillana was analysed by the author at the University of Western Australia's Centre for Archaeology in 2002-2003. Field drawings by Strawbridge and the author's sediment particle size analysis indicate that four stratigraphic units exist at Marillana A [30]. There is no indication of bioturbation such as burrowing or erosion. Strawbridge's field notes suggest that water does not flow through the site. Pieces of charcoal were taken from sediment samples for radiocarbon dating to determine the chronology of the stratigraphic units (dates are presented as uncalibrated conventional radiocarbon ages). Excavated square 9B is focussed on here because it had adequate charcoal for dating and a relatively large stone artefact assemblage, unlike square 11B. Rates of stone artefact discard at Marillana A suggest that the site was most intensively used between 9,000 BP and 3,000 BP (Figure 2).

Insert figure 2 about here: "Figure 2. North section and stone artefact discard at excavated square 9B"

The stone artefact pattern observed at Marillana A suggests that there was a change in the function of the site, the frequency of visits to the site or the duration of visits to the site. These three variables are closely related and may have all changed at once, but by proposing three discrete explanations it may be possible to identify what variable, if any, was most important for the increase in stone artefact discard. Firstly, there may have been a change in the function of the site. This means that the frequency and duration of visits does not change, but that different types of activities were carried out after 13,000-9,000 BP (for example, an increase in stone artefact manufacture and a decline in the processing of organic materials). Secondly, there may have been a change after 13,000-9,000 BP from more mobile populations with highly curated technologies (where artefacts have a relatively long use-life and are frequently repaired and resharpened) to less mobile populations with expedient technologies (where artefacts are made with a minimum of production effort and discarded after a relatively brief use-life) [33, 38]. This means that the frequency and duration of visits to Marillana A increases and the stone artefact technology changes, perhaps in response to environmental change. The third explanation is a simple increase in the frequency of site use, with no substantial changes in site function or mobility. This might result from increases in population density in the region. Physical and chemical properties of archaeological sediments at Marillana A were analysed along with technological attributes of the stone artefact assemblage to determine if one of these explanations is more suitable than the others.

The potential of geoarchaeological methods at Marillana A

The two key variables of occupation intensity required to discern between the three explanations are frequency of visits and average duration of each visit. To investigate these variables, analysis of phosphorus concentrations and magnetic susceptibility of archaeological sediments was undertaken. Concentration of phosphorus in archaeological sediments has been used as an indicator of occupation intensity on temporal scales [2, 8, 28, 32, 36, 40] and spatial scales [6, 7, 11, 24, 29, 34, 35, 45, 46, 47] at historic and prehistoric sites.

Phosphorus concentration is useful as an indicator of human occupation because it is contained in organic matter that is deposited by humans in proportion to the intensity of site occupation [36, 45]. Phosphorus is especially useful because, while carbon and nitrogen and other elements abundant in organic material can be transformed into inorganic forms that are not bound to the soil (for example, CO_2 for carbon and ammonium nitrate and N_2 for nitrogen), phosphorus is rapidly fixed to the soil under both acidic and alkaline conditions and tends to remain stable in soils for very long periods with negligible horizontal and vertical migration and no gaseous escape [27, 36, 40, 45]. Phosphorus becomes enriched in the soil relative to carbon and nitrogen as organic matters decay and carbon and nitrogen compounds leave the soil. Once it has entered the sediment, phosphorus may undergo a series of transformations, including complexation of free ions with other constituents of the sediment, such as aluminium and iron oxides, clays and organic colloids, and removal through leaching, erosion and deflation. Carbon concentration was also measured at Marillana A as an indicator of the residual organic matter.

Magnetic susceptibility analysis has been used by archaeologists over spatial [12] and temporal [4, 9, 13, 14] scales as a measure of the intensity of firing of archaeological sediments and objects [26]. Changes in magnetic susceptibility of sediments occur when magnetic grains become concentrated or diluted through the addition or removal of materials and through transformation of minerals [18]. Transformation of minerals from weakly susceptible to strongly susceptible can occur by weathering, pedogenesis, bacterial respiration, chemical reduction during organic matter decay and chemical oxidation during firing [18, 39]. As the amounts of organic matter in inland Pilbara rockshelters are typically very low below the surface, weathering, pedogenesis and firing were considered to be the most significant sources of enhanced magnetic susceptibility. Pilbara soils are rich in iron, mainly in the form of antiferromagnetic haematite and goethite [44]. Haematite (α-Fe_2O_3) in soils is converted to magnetite when heated in a reducing atmosphere and magnetite (Fe_3O_4) is converted to maghemite (γ-Fe_2O_3) during cooling in an oxidising atmosphere [43]. Magnetite and maghemite are ferrimagnetic with mass susceptibilities two to three orders of magnitude greater than haematite [18]. The high concentration of haematite in Pilbara soils suggests that changes in the intensity of sediment heating at Marillana A will produce clearly detectible changes in the magnetic susceptibility of the sediments.

At Marillana A periods of longer occupation were expected to be characterised by sediments with high magnetic susceptibility because of the frequent firing of sediments in hearths. If the site is occupied for several days consecutively (for example, in the course of seasonal occupation) the occupants probably imposed spatial structure with a clearly defined hearth area where fires for cooking and warmth were located. Conversely, periods of brief and infrequent occupation episodes (for example, during hunting or foraging trips) were expected to be characterised by sediments with low magnetic susceptibility because the sediments were not frequently fired, if at all, and fired sediments would be diluted by the addition of non-fired sediments and the removal of the fired sediments by natural site formation processes. The spatial patterns imposed on the site during the brief visits may not have been robust or consistent enough to survive post-depositional processes operating between visits. This means that if fires were made during brief visits, the magnetic susceptibility of the sediments was probably not significantly affected.

The combined use of phosphorus concentrations and magnetic susceptibility provides data to test the three explanations for human behaviour at Marillana A. Phosphorus concentrations may be responsive to both duration and frequency of human habitation, giving a general index of occupation intensity. On the other hand, magnetic susceptibility is probably most sensitive to duration of visits because of its relationship to firing activity and the structure of habitation areas. If a change in site function is the best explanation for the artefact discard pattern then no change in phosphorus concentrations or magnetic susceptibility is expected after 13,000-9,000 BP. This result would reflect a similar intensity of site use throughout the history of occupation of Marillana A. The change in site function should be apparent in other data, such as the stone artefact and organic assemblages. If a change in mobility is the best explanation then changes in both phosphorus concentrations and magnetic susceptibility are expected after 13,000-9,000 BP. This would indicate an increase in sedentism (frequency and duration of visits) which should be accompanied by an expedient artefact technology after 13,000-9,000 BP. If the third explanation, a change only in the frequency of visits, is the best explanation then changes only in phosphorus concentrations are expected after 13,000-9,000 BP. No change in magnetic susceptibility is expected because the duration of visits, as a proxy for the function of the site, remains unchanged.

Analytical Methods

Stone artefacts

The analysis of stone artefacts at Marillana A focussed on understanding the technology and economics of artefact production and curation to investigate changes in mobility levels and site function. To investigate these variables the stone artefact assemblage was classified according to Sullivan and Rozen's

[41] debitage typology and a series of technological and metric variables were recorded for each artefact as described in Marwick [30].

X-ray fluorescence

X-ray fluorescence (XRF) was chosen for quantitative analysis of phosphorus in archaeological sediments at Marillana A. Previously used methods such as ignition methods [36] and acid extraction colorimetry [2, 11, 24, 27, 32, 45] were not appropriate because quantities of phosphorus in Pilbara soils, as previously measured by Bentley *et al.* [5] are below the detection limit of these methods. ICP-MS was not used because the determination of phosphorus using this technique is problematic, time consuming and expensive [16, 17].

XRF is an attractive technique because it is accurate, relatively cheap, easy to use, has short processing times and very low detection levels for total phosphorus and a range of other elements. The fundamental principle behind XRF is that when electrons of a particular element are excited by x-rays they emit or *fluoresce* a spectrum of x-rays that is specific to that element [25, 31, 42]. Although XRF is frequently used for sourcing archaeological obsidian, glass, ceramic and metal [10, 22, 23, 37] it does not appear to have previously been used in the analysis of archaeological sediments. Following Norrish & Chappell [31], sediment samples were prepared by combining 0.007±0.0005 g of finely ground sediment with 7±0.0005 g of x-ray flux (lithium tetraborate and lanthanum oxide) and heating at 1050°C in a muffle furnace. After 45 minutes in the furnace the molten sediment-flux mixture was poured into a platinum bead mould and left to cool. The fusion beads were analysed using a fully automated Phillips PW1400/00 sequential x-ray spectroscope with a PW1730/10 constant potential x-ray generator calibrated using OREAS 42p, quartz and titanium dioxide standards. The machine was controlled by the Phillips X40 programme for MS DOS which also calculated the total element concentrations.

Carbon concentration

Total carbon concentrations were determined using the computer controlled LECO CHN 1000 high frequency induction furnace. The furnace converts the carbon (including carbon in carbonates) present in the sediment to gaseous CO_2 which is measured by infrared absorption. A calibration curve of 10% EDTA was established before sediment samples of 350 mg each were analysed. Petra's Standard Soil was used as a standard.

Magnetic susceptibility

The magnetic susceptibility analysis was conducted using the Bartington MS2 susceptibility meter and Bartington MS2B 36 mm internal diameter dual frequency sensor according to the procedure in Gale and Hoare [18]. Sediment samples were taken from the $<-1\phi$ fraction and analysed in 6 cm^3 plastic cubes at normal sensitivity.

Soil pH, soluble salt concentration and organic material concentration

Soil pH was measured as an indicator of preservation conditions because high acidity generally limits the activity of organisms that cause decay. Soil pH was measured after Alymore *et al.* [3] in a 1:5 sediment to de-ionised water solution (tumbled for 24 hours and centrifuged for 30 minutes at 2000 rpm) with a Cyberscan electrometric pH meter calibrated using buffer solutions of pH 4, pH 7 and pH 10. Sediment moisture is also an indicator of preservation conditions but was not measured here because the archaeological sediment samples have been in storage for ten years and their moisture content has probably changed over time. Soluble salt concentrations, which can increase with increased firing activity because ash contains the salts of the combusted organic material (Gilkes pers. comm. 2002), were measured following Alymore *et al.* [3] in a 1:5 sediment to de-ionised water solution (tumbled for 24 hours and centrifuged for 30 minutes at 2000 rpm) with a Cyberscan electrometric conductivity meter calibrated to 1413 $\mu S\ cm^{-1}$. Sedimentary organic material (including charcoal and faunal remains) was extracted from sieves in the field and during laboratory sorting by hand and soil organic material was determined by the loss on ignition test.

Results

Stone artefacts

The results of stone artefact analysis are complex but generally support only the second and third explanations for the change in artefact discard. Chi-square tests show that there are no significant changes in the proportions of each debitage type over time (Table 1) despite an increase in the proportions of chert and chalcedony and decline in the proportions of silcrete over time (Table 2). A closer look at technological variables shows that there are no significant changes in multiple variables indicating substantial shifts in lithic technology (Table 3). These data rule out the first explanation, change in the function of the site, and support the third explanation, simple increase in the frequency of site use. If the pattern of retouched artefacts in Table 4 is interpreted as evidence of a curation-mobility relationship then the frequency of residential moves was reduced at 13,000-9,000 BP when the proportion of retouched artefacts is lowest. An expedient assemblage is also indicated by the low proportion of retouched pieces at 9,000-3,000 BP (Table 4). This suggests that a change from curated to expedient technologies (the second explanation) may also explain the change in artefact discard rates.

Insert table 1 about here: "Table 1. Chi-square tests on the differences in the numbers of debitage types between stratigraphic units"

Insert table 2 about here: "Table 2. Chi-square tests on the numbers of chert, chalcedony and silcrete artefacts between stratigraphic units"

Insert table 3 about here: "Table 3. Summary of chi-square tests on technological variables"

Insert table 4 about here: "Table 4. Summary of all artefacts with secondary working"

If changes in mobility explain the pattern at Marillana A then stratigraphic unit two, with the highest density of artefacts, should be the most expedient assemblage with the lowest proportion of retouched artefacts. In fact the lowest proportion of retouched artefacts occurs in stratigraphic unit three at 13,000-9,000 BP which has very few artefacts. An ethnographic analogy may indicate why the curation-mobility relationship does not explain the change in discard rates at Marillana A. In an ethnoarchaeological study of the mobile arid-land dwelling Nyanunyatjara, Ngatatjara and Ngatjara language speakers of the Australian Western Desert, Gould *et al*. [20] observed a number of features of stone artefact manufacture and use that interfere with the mobility-curation relationship. They describe a range of artefacts that are exclusively used by men and are kept hidden when not in use because they are not allowed to be seen by women, children and uninitiated males [20]. Examples of these tools include a small engraving tool used for making incised decorations on sacred boards and decorated spearthrowers and long flakes used to circumcise males [20]. This study suggests that stone artefacts may have a social function making their level of curation independent of the frequency of residential moves. Gould *et al.* [20] also describe stockpiling of raw materials and trading by these hunter-gatherers, procurement strategies described by Parry and Kelly [33] to be typical of less mobile groups.

A particularly interesting detail noted by Gould *et al.* [20] is the combination of curated and expedient technology used by Western Desert Aboriginal people. They describe two types of adzes (*tula* and *burren*) used for woodworking that are standardised and frequently retouched. They also observe that lithic procurement by Western Desert Aboriginal people can result in a ratio of flake to waste pieces of 1:200-600, generating 'the tremendous quantities of unused stone flakes which one characteristically finds on the surface of Aboriginal quarries' [19, 20]. Gould *et al.* [20] observe that 'the chipping of stone tools is regarded by these people as an art of little importance'. They describe an Aboriginal man who picked up a used artefact and recycled it by hafting it to his spear-thrower and several instances of Aboriginal people who 'simply seize a stone, use it for an immediate purpose, and discard it'. The significance of these ethnoarchaeological observations is that highly mobile Australian Aboriginal people in arid environments use a combination of curated and expedient stone artefact technologies that are not always related to measures of mobility such as frequency of residential moves. This implies that the mobility-curation relationship proposed by Parry and Kelly [33] and Shott [38] may not be applicable to artefact assemblages, such as at Marillana A, produced by Aboriginal people inhabiting the inland Pilbara.

To summarise, the curation-mobility relationship does not appear relevant here and a change in the function of the site is also not supported by the stone artefact data which shows that despite substantial changes in discard rates there were no significant changes in artefact manufacturing and economising techniques. This suggests that simple increase in the site use is the best explanation but with the small sample size only a low level of confidence can be placed in the stone artefact artefact data by itself.

Sedimentary and soil organic material and soluble salts

These basic sediment variables provide another avenue to test which of the three explanations best fits the data. The distribution of sedimentary and soil organic material at Marillana A appears to be strongly related to preservation rather than artefact discard (Figure 3). On the other hand, the distribution of charcoal and faunal remains more closely follows the distribution of stone artefacts (Figure 4). The pattern of soluble salt concentration (Figure 5) does not have the same curve of the sedimentary and soil organic material but shows a similar peak in stratigraphic unit two to charcoal and faunal material. The XRF analysis showed relatively high concentrations of calcium in sediment from excavation units 21-27, suggesting that the peak in soluble salts in those units is a result of high concentrations of gypsum crystals ($CaSO_4.2H_2O$, also identified microscopically) in the sediment. Gypsum was probably concentrated there under conditions of reduced sedimentation and increased erosion at the terminal Pleistocene. The correlation of charcoal and soluble salts is probably due to the formation of salts during the combustion of organic material. These data suggest that the distribution of charcoal, faunal remains and soluble salts are related to more to human occupation and stone artefact discard than decay. This pattern rules out an explanation of functional change at the site such as an increase in tasks involving stone artefacts and a decline in the processing of organic materials. It does not distinguish between the second (change from curated to expedient stone artefact technology) and third (simple increase in site use) explanations for change.

Insert figure 3 about here: "Figure 3. Sedimentary organic material, soil organic material and pH distributions"

Insert figure 4 about here: "Figure 4. Charcoal and faunal remains distributions"

Insert figure 5 about here: "Figure 5. Soluble salt distribution"

Analysis of element concentrations

Figure 6 shows the concentrations of P and C measured in each analysed sample. The step-like reductions in P and C suggest that gradual geological processes such as erosion, leaching and decomposition have not substantially influenced the distributions of these elements.

Insert figure 6 about here: "Figure 6. Concentrations of P and C at Marillana A"

Analysis of magnetic susceptibility

Figure 7 shows that a change in magnetic susceptibility occurs at excavation units 19-24 but that there is little change in the frequency dependency. The XRF evidence shows that changes in the concentration of iron, the main contributor the magnetic properties of the sediment, do not explain the change in magnetic susceptibility. The change is probably explained by the increase in gypsum which is a diamagnetic material that reduces magnetic susceptibility by diluting magnetic materials, having little effect on ratios of magnetic parameters such as frequency dependency [18].

Insert figure 7 about here: "Figure 7. Magnetic susceptibility and frequency dependency at Marillana A"

Magnetic susceptibility can be a proxy variable for palaeoclimate because changes in climate influence changes in soil formation [13, 14, 15]. There is no direct palaeoenvironmental evidence from the Pilbara for the period that Marillana A is occupied, but pollen taxa recovered from two dated peat cores in swamps in the Great Sandy Desert, about 500 km northeast of the inland Pilbara, suggests that present conditions were established by 7000 BP and climatic conditions have been stable since [48]. Lake sedimentation records and pollen sequences from around Australia suggest that climatic conditions were generally wetter and warmer than today from 10,000 BP to 7000 BP [1, 21]. In this case it appears that the climate change at about 7000 BP was not large enough not influence magnetic susceptibility at Marillana A.

Discussion

Table 5 shows the calculation of Pearson's product-moment correlation coefficient for chemical and cultural variables at Marillana A. Excavation unit 21 was excluded from the calculations as an outlier because of the unusually high concentration of P that probably resulted from the reduced sedimentation at the interface of the roof fall unit and stratigraphic unit two. Strong positive correlations exist between P and C concentrations and artefact density. A moderate correlation exists between soluble salt concentration and artefact density but the strong positive relationship between soluble salts and pH suggests that one of the soluble salts affects pH. Very weak correlations between pH, P and C suggest that preservation conditions have not significantly influenced the retention of these elements in the sediments. The strong significant correlations between phosphorus and carbon concentrations and artefact density suggest that the increased discard of artefacts coincided with an increase in the intensity of site occupation.

Insert table 5 about here: "Table 5. Correlations between chemical and cultural variables"

The correlations between sediment magnetic data and other data are generally weak (Table 6). The weak correlation between magnetic susceptibility and stone artefact discard suggests that soil magnetic characteristics were not influenced by human occupation. The weak correlation of soluble salts and magnetic susceptibility is probably because the soluble salt distribution are influenced by human occupation and have a similar pattern to the stone artefact discard. The weak correlation between soil organic material and magnetic variables suggests that soil magnetic qualities were not significantly influenced by pedogenesis or chemical reduction during organic matter decay. The moderate positive correlation between frequency dependency and charcoal density suggests that the magnetic variables are sensitive to firing of the sediments. The poor match between the distributions of charcoal (Figure 4) and frequency dependency (Figure 7) and the low correlation between charcoal and magnetic susceptibility indicates that this relationship is of limited relevance at this site. The weak correlations of the magnetic data with other variables suggest that the intensity of sediment firing, and probably the duration of visits, did not change at Marillana A.

Insert table 6 about here: "Table 6. Correlations between magnetic and other variables"

The combination of the XRF and magnetic susceptibility data with stone artefact and other data suggest that a simple increase in the frequency of site use, with no substantial changes in mobility or site function, is the best explanation for the changes at Marillana A. These element and magnetic data suggest that the function of Marillana A as a site of brief visits appears not to have changed throughout the history of its occupation although the frequency of visits increased substantially between 9,000-3,000 BP.

Conclusions

The results described above suggest that the most parsimonious explanation for the evidence at Marillana A is that there was a simple increase in the frequency of site use with no substantial changes in site function or mobility. The increase in frequency of site use at Marillana A probably resulted from an increase in population density in the inland Pilbara region. An increase in population density and occupation magnitude means either that same number of people are engaging in more activities or that there are more people doing the same number of activities. With the available evidence it is difficult to distinguish between these two explanations. In any case, this increase is in general agreement with the broader pattern of increases in occupation magnitude and in the rate of newly occupied sites in the inland Pilbara at around 3,600 BP [30]. At this time there are also new forms of stone artefacts introduced (adzes and backed artefacts) and increases in the production of rock art in the northwest of Western Australia [30]. These archaeological changes may be associated with transformations of cultural systems relating to group interaction, boundary maintenance and gender roles. These changes in cultural systems are probably adaptive responses to increased occupation magnitude, which may have resulted from climate change in an adjacent region.

While the data presented here are specific to one site, the results suggest that XRF and magnetic susceptibility are generally useful techniques for understanding change in human behaviour at stratified sites, especially in areas where cultural materials from excavated assemblages are sparse or ambiguous. These geoarchaeological techniques are robust indicators of occupation intensity when combined with more direct evidence such as stone artefacts, faunal remains and charcoal. In particular, XRF analysis of phosphorus concentrations has been shown to be an accurate indicator of changes in human occupation magnitude.

Further work with these techniques on other sites in different sediments, such as coastal sites, would give a better understanding of the reliability of sedimentary variables as proxy indicators of human behaviour. On sites in similar soil it may be possible to combine data from many sources, including usewear and residue analysis, to create detailed profiles of site use. In addition, the chronological resolution at Marillana A is currently quite coarse and further work will demonstrate how sensitive these methods are to fine-grained changes in site use.

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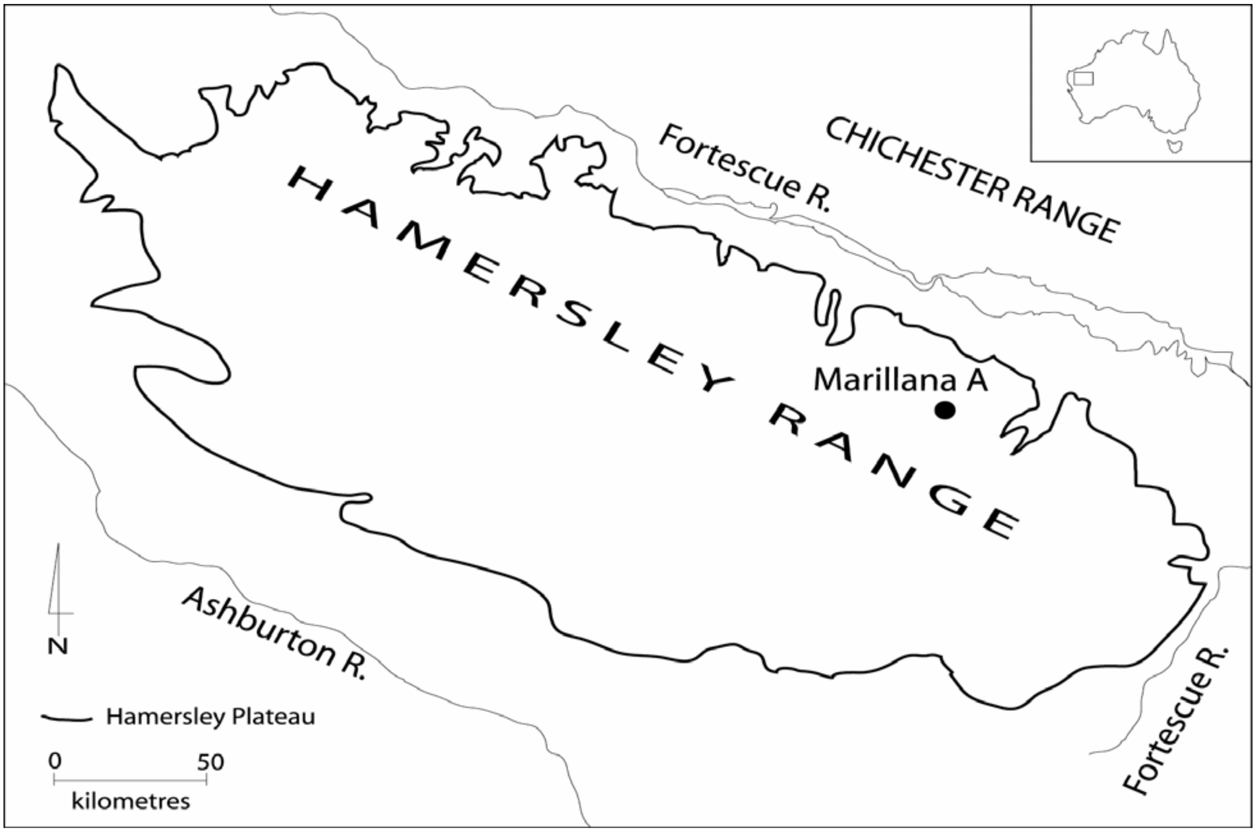
Captions for tables and figures

Figure 1



HAMERSLEY RANGE
Fortescue R.
CHICHESTER RANGE
Marillana A
Ashburton R.
Fortescue R.
N
Hamersley Plateau
0
50
kilometres

Figure 2

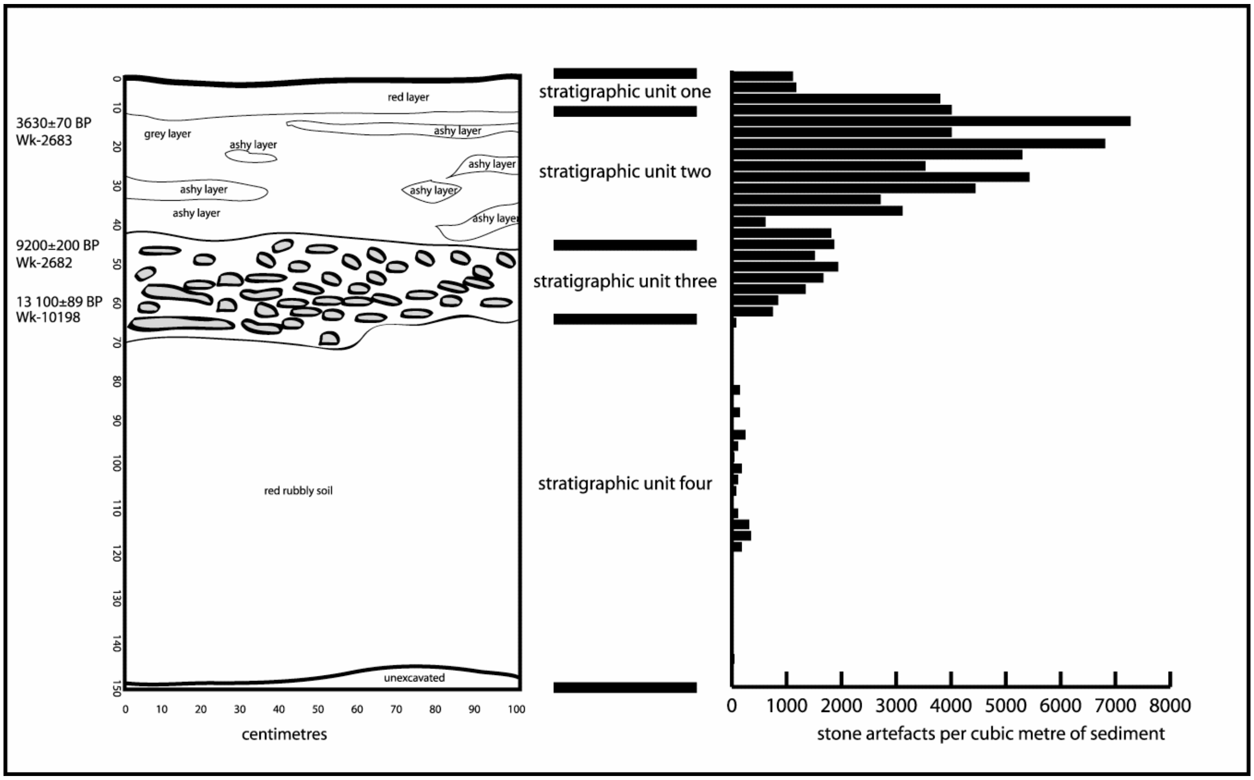

3630±70 BP
Wk-2683
9200±200 BP
Wk-2682
13 100±89 BP
Wk-10198
red layer
grey layer
ashy layer
red rubbly soil
unexcavated
centimetres
stratigraphic unit one
stratigraphic unit two
stratigraphic unit three
stratigraphic unit four
0 1000 2000 3000 4000 5000 6000 7000 8000
stone artefacts per cubic metre of sediment

Figure 3

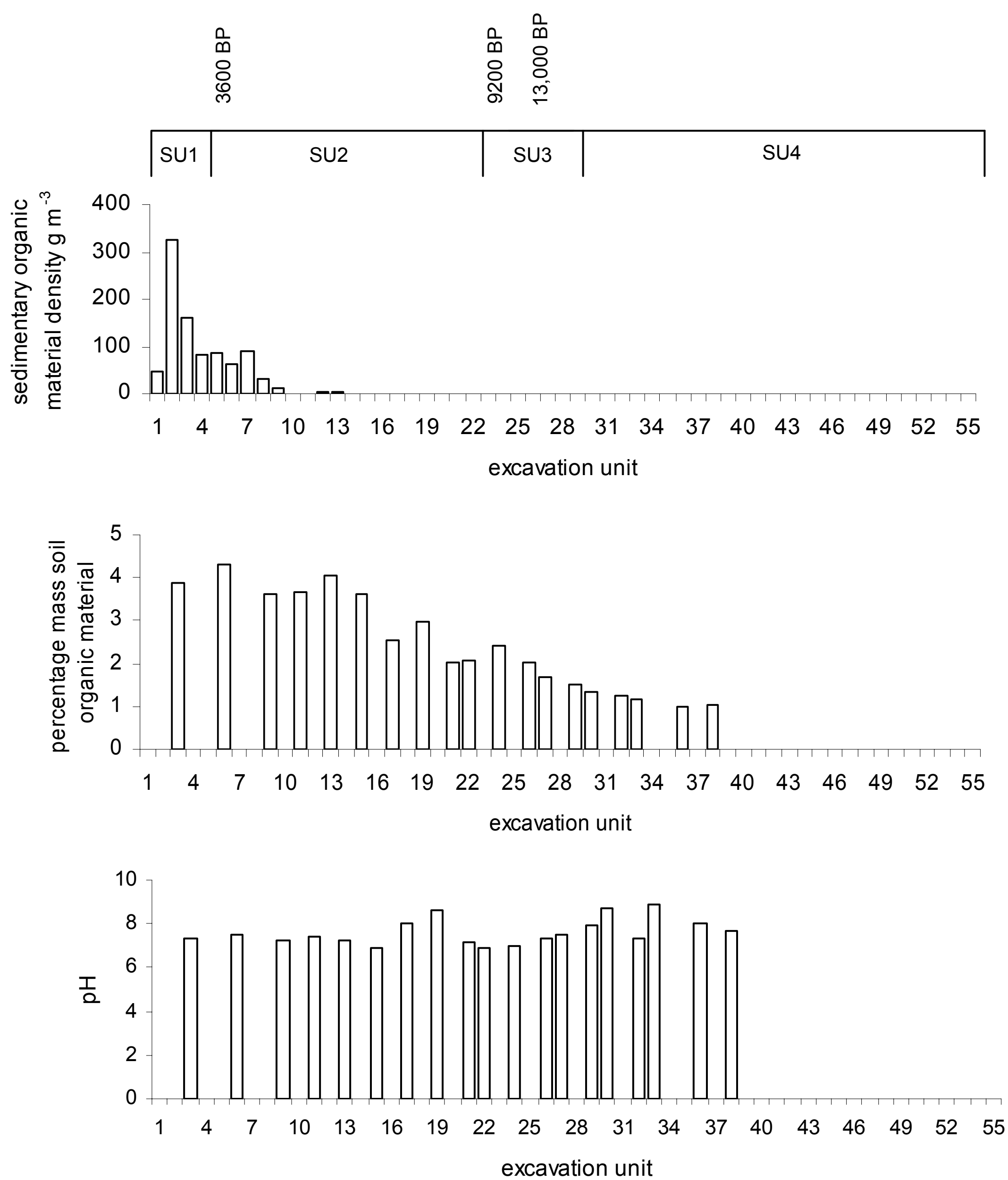

3600 BP
9200 BP
13,000 BP
SU1
SU2
SU3
SU4
sedimentary organic material density g m-3
excavation unit
percentage mass soil organic material
excavation unit
pH
excavation unit

Figure 4

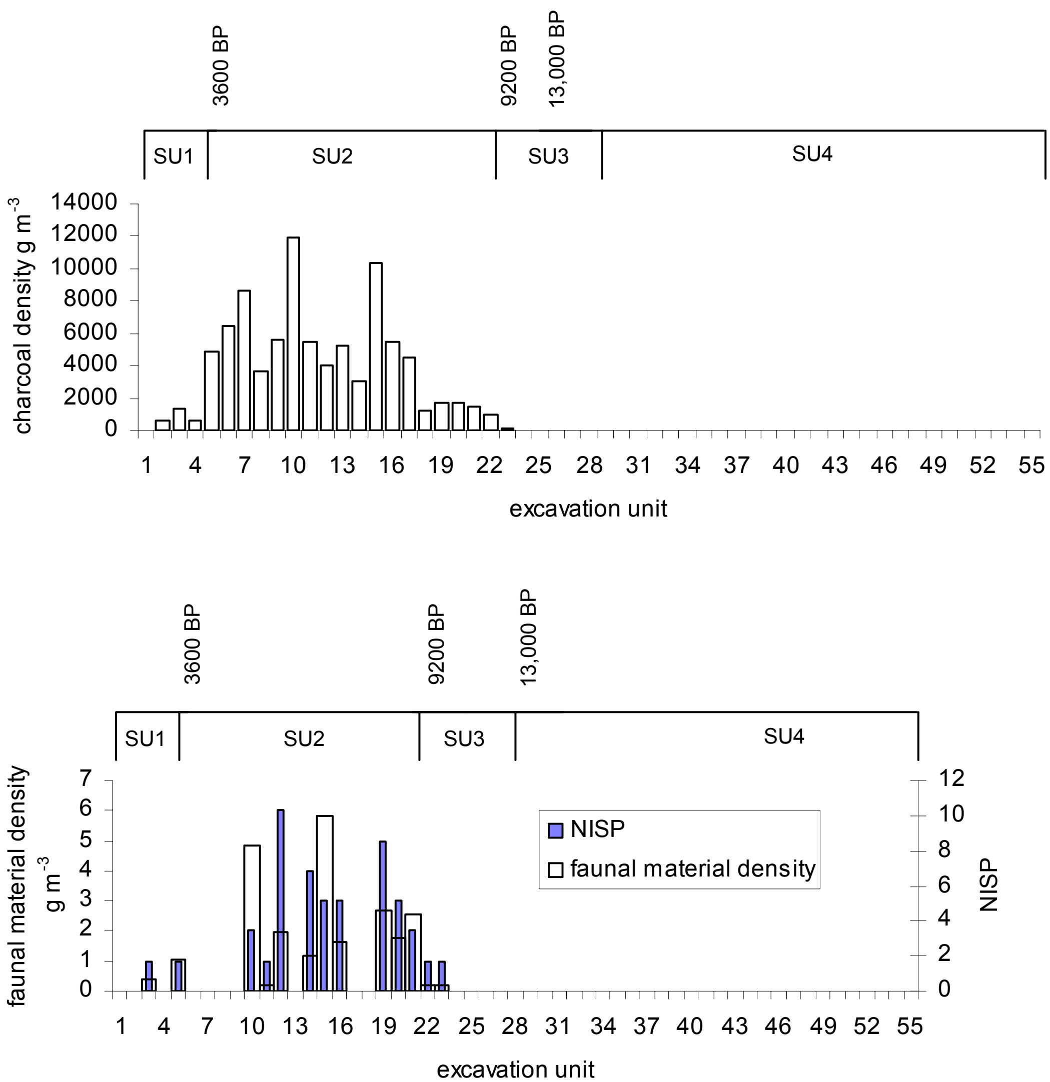

3600 BP
9200 BP
13,000 BP
SU1
SU2
SU3
SU4
charcoal density g m-3
excavation unit
faunal material density g m-3
NISP
faunal material density
excavation unit

Figure 5

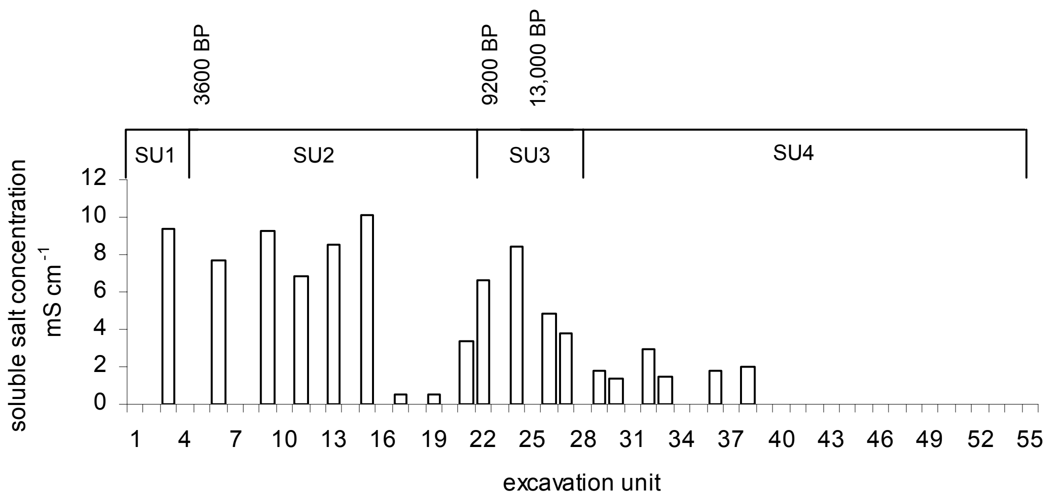
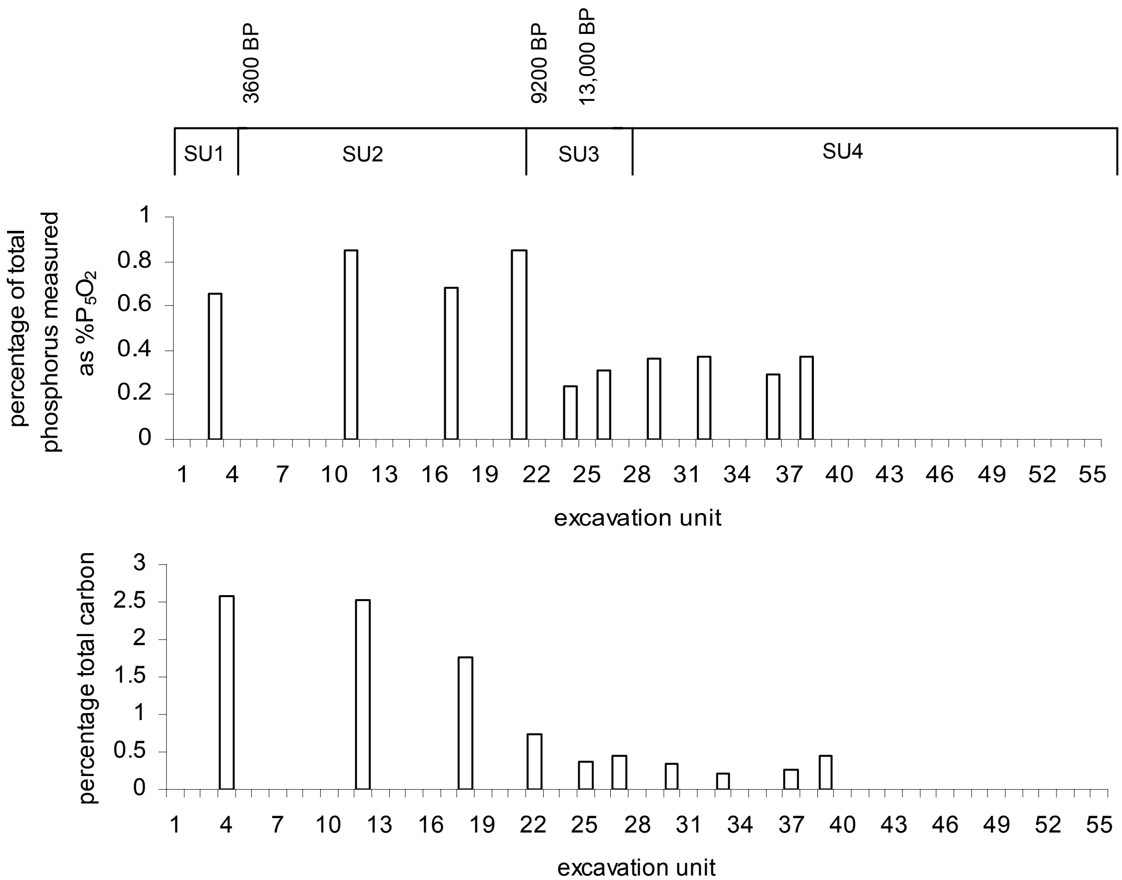

3600 BP
9200 BP
13,000 BP
SU1
SU2
SU3
SU4
soluble salt concentration
mS cm-1
12
10
8
6
4
2
0
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
46
49
52
55
excavation unit

Figure 6



3600 BP
9200 BP
13,000 BP
SU1
SU2
SU3
SU4
percentage of total phosphorus measured as %P_5O_2
1
0.8
0.6
0.4
0.2
0
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55
excavation unit
percentage total carbon
3
2.5
2
1.5
1
0.5
0
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55
excavation unit

Figure 6

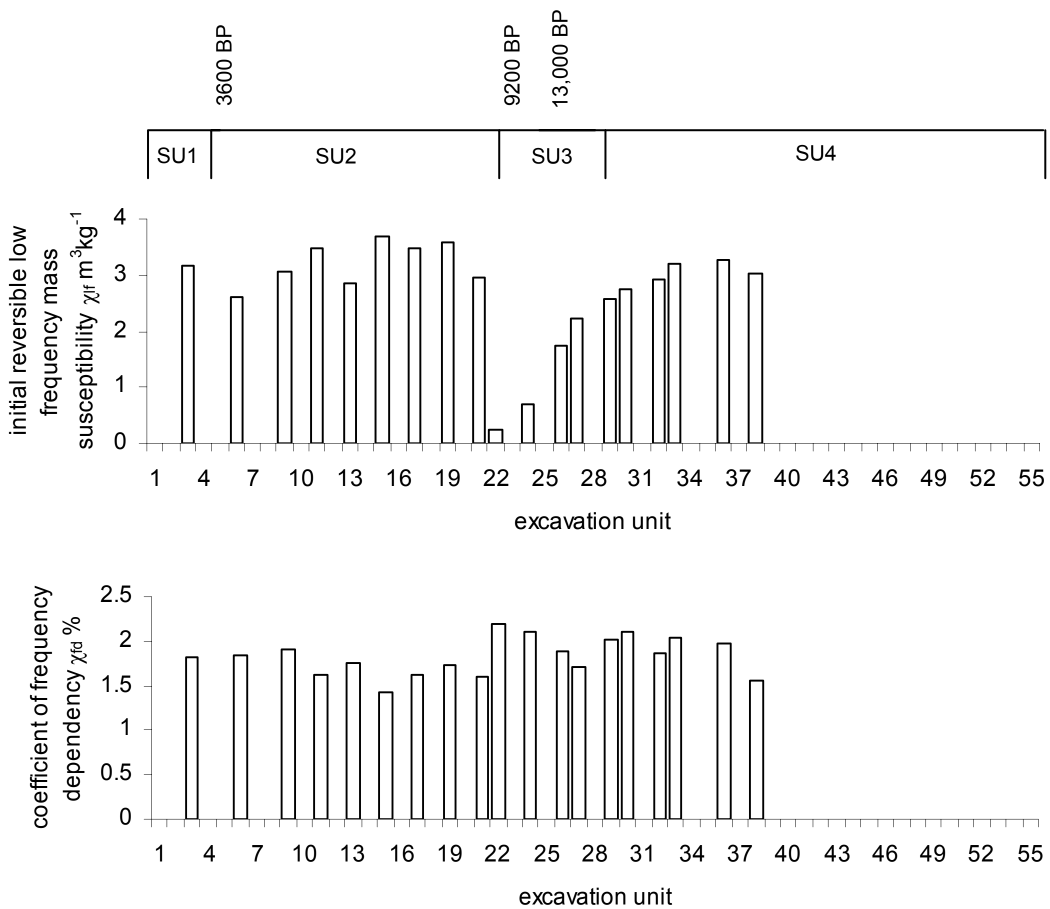

3600 BP
9200 BP
13,000 BP
SU1
SU2
SU3
SU4
initial reversible low frequency mass susceptibility χ_{lf} m^{3}kg^{-1}
4
3
2
1
0
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55
excavation unit
coefficient of frequency dependency χ_{fd} %
2.5
2
1.5
1
0.5
0
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55
excavation unit

Table 1

SU	χ^2	df	$p(H_0)$	reject H_0?
1:2	1.401	3	0.705	no
2:3	0.595	3	0.897	no
3:4	2.130	3	0.545	no

SU= stratigraphic unit
χ^2= chi-square
df= degrees of freedom
$p(H_0)$= probability that the null hypothesis (that there is no difference) is true

Table 2

Chert

SU	χ^2	df	$p(H_0)$	reject H_0?	ϕ	C_{adj}
1:2	12.504	1	0.0004	yes	0.105	0.145
2:3	4.594	1	0.032	yes	0.513	0.051
3:4	2.558	1	0.109	no	na	na

Chalcedony

SU	χ^2	df	$p(H_0)$	reject H_0?	ϕ	C_{adj}
1:2	4.189	1	0.041	yes	0.061	0.084
2:3	15.747	1	7.21×10^{-5}	yes	0.560	0.094
3:4	2.163	1	0.141	no	na	na

Silcrete

SU	χ^2	df	$p(H_0)$	reject H_0?	ϕ	C_{adj}
1:2	39.099	1	4.03×10^{-10}	yes	-0.186	0.254
2:3	7.103	1	0.007	yes	0.584	0.063
3:4	0.405	1	0.524	no	na	na

SU=	stratigraphic unit
χ^2=	chi-square
df=	degrees of freedom
$p(H_0)$=	probability that the null hypothesis (that there is no difference) is true
ϕ=	Phi coefficient (direction of association)
C_{adj}=	Pearson's contingency coefficient adjusted (strength of association)

Table 3

	Technological variable	Chert	Chalcedony	Silcrete
Mass		↑ after 3000 BP	no change	↓ after 13,000 BP
Termination	Feather	no change	no change	no change
Platform surface	Flat	no change	no change	no change
	Facetted	no change	↓ after 3000 BP	no change
	Cortical	no change	no change	no change
Platform type	Wide	no change	no change	no change
	Focalised	no change	no change	no change
	Gull	no change	no change	no change
Overhang removal	Flakes with overhang removal	no change	no change	no change
Reduction level	Flakes with >1 dorsal flake scar	no change	no change	↓ after 9000 BP
	Flakes with distal and lateral flake scars	no change	no change	no change
	Flakes with <10% cortex	no change	no change	no change
	Flakes with 10-50% cortex	no change	no change	no change
	Flakes with >50% cortex	no change	no change	no change

Table 4

Stratigraphic unit	1	2	3	4
Years BP	0-3000	3000-9000	9000-13,000	>13,000
Total number of artefacts	219	903	48	57
Total number of artefacts with retouch/usewear	13	20	0	5
Number of artefacts with retouch/usewear that are backed	1	1	0	0
Total number of cores	0	3	0	0
% of artefacts with retouch/usewear	5.9	2.2	0.0	8.8
Chi-square	9.081	9.089	na	na
$p(H_0)$	0.003	0.003	na	na
Significant change?	yes - increase	yes - decrease	na	na

Table 5

	C	pH	soluble salts	artefacts
P	**0.785**	0.053	0.257	**0.800**
C		0.019	0.416	**0.976**
pH			**0.825**	0.130
soluble salts				0.522

Bold type indicates $p(H_0) < 0.05$

Table 6

	artefacts	soluble salts	charcoal	soil organic material
χ_{lf}	0.351	0.282	0.382	0.174
χ_{fd}	0.311	0.067	0.535	0.321

χ_{lf}= initial reversible low frequency mass susceptibility
χ_{fd}= coefficient of frequency dependency
Bold type indicates $p(H_0) < 0.05$