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Integrating Geoarchaeology and Magnetic Susceptibility at Three Shell Mounds: A Pilot Study from Mornington Island, Gulf of Carpentaria, Australia

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Abstract

In coastal areas of the globe, open shell matrix sites are commonly used to establish regional chronologies of human occupation and identify patterns of cultural change, particularly for the Holocene, post-sea-level stabilisation period. Despite this, many basic sedimentary analyses that are routinely applied to rockshelter deposits (e.g. geophysical characterisation, particle size etc) are rarely applied to these sites. Magnetic susceptibility, occasionally used in rockshelters, has never been used to investigate shell matrix sites in Australia, despite several international studies identifying its efficacy for other types of open sites. This paper reports a pilot project applying a range of conventional sedimentary and archaeological analyses, as well as magnetic susceptibility at three anthropogenic shell mounds on Mornington Island, Gulf of Carpentaria, Australia. Results are compared to, firstly, assess site integrity and, secondly, to ascertain whether magnetic signatures are related to cultural or natural site formation processes. The results establish that the mounds were repeatedly visited, despite the archaeological evidence, including radiocarbon ages, suggesting effectively 'instantaneous' deposition. This has important implications for studies of other shell mounds where the limitations of radiocarbon dating precision may also mask multiple deposition events.

Highlights

- Magnetic susceptibility is used to investigate shell matrix sites in Australia.
- A pilot project applying magnetic susceptibility at three anthropogenic shell mounds.
- Mounds were repeatedly visited, despite evidence that suggests an 'instantaneous' deposition.
- Limitations of radiocarbon dating precision may also mask multiple deposition events.

Introduction

In Australia, shell matrix deposits dominate the Holocene archaeological record in coastal areas. Understanding the formation history of some of these sites—for example, the large shell mounds of Cape York Peninsula—is relatively clear-cut, as clearly alternating layers of shell-rich and shell-poor layers make it clear that there have been different periods of accumulation (Morrison 2010, 2013). In contrast, many smaller mound sites have no such evidence for stratigraphic layering, instead appearing as a single homogenous deposit dominated by shell, characteristically with a thin sediment-rich uppermost unit, with nuanced, if any, shifts in dominant faunal composition (Faulkner 2013; Morrison 2013; Rosendahl 2012; Shiner *et al*. 2013). From such deposits researchers typically obtain, at best, two radiocarbon determinations (one for the surface and one for the base), which often produce ages that are statistically the same with large error margins, and an absence of local marine reservoir calibration values applied (cf. Ulm and Reid 2000). These sites can be interpreted as representing single deposition events (Stein *et al*. 2003:313), although there is limited evidence on which to base these interpretations.

In the last 2000 years shell mounds emerged as a conspicuous feature of the archaeological landscape across northern Australia (Ulm 2011). Over 500 mounds occur on mangrove-lined estuaries in the Weipa area alone, with the largest in excess of 12 m high, although most are less than 1 m (Bailey 1994; Morrison 2010, 2013). All mounds investigated in the southern Gulf of Carpentaria (Robins *et al*. 1998; Rosendahl 2012), Weipa (Bailey 1999) and Princess Charlotte Bay (Beaton 1985) are dominated by the cockle *Anadara granosa*, which comprises more than 95% of the shell weight, with lower representation of mangrove-associated gastropods (*Telescopium* sp., *Terebralia* sp.) and bivalves (*Polymesoda* sp.), as well as occasional fish and terrestrial animal bones and stone artefacts. For Princess Charlotte Bay, Haberle and David (2004:172) linked the appearance of shell mounds to the emergence of new centralised consumption places, with associated novel foraging and disposal practices. Although there are earlier examples, the proliferation of shell mounds is associated with marked increases in the number of sites in the late Holocene (Ulm 2013; Ulm and Reid 2000; Williams *et al*. 2010) which are interpreted as implying higher populations (Williams 2013).

To date, studies of Australian archaeological shell deposits have focused on macroscopic faunal remains (e.g. Faulkner 2013; Ulm 2006), rather than microscopic remains (cf. Rosendahl *et al.* 2007). Yet, despite a range of basic sedimentary analyses being routinely applied to rockshelter deposits, rarely have Australian researchers focused a similar level of attention towards the sedimentary matrices of shell matrix sites (but see Hughes and Djohadze 1980 for an exception), especially with regards to geophysical applications such as magnetic susceptibility (Lowe 2012). In this paper, we present magnetic susceptibility and other geoarchaeological data, to explore issues of formation processes of three small shell mounds from the Gulf of Carpentaria. The results demonstrate that integrating geophysics with other techniques is an effective means by which to test previous interpretations of shell mound occupation and deposition. Further it highlights the importance in using such analyses to understand human occupation and settlement patterns in this region.

The three study sites, Guttapercha, Munburlda and Mala Katha, are located in the Gulf of Carpentaria, an epicontinental sea situated between northern Australia and Papua New Guinea containing numerous offshore islands and archipelagos, of which the Wellesley Islands Group is but one (Figure 1). Comprising more than 23 islands, the Wellesleys are dominated by Mornington Island, covering 966.5 km^2. With the exception of a few low elevation (<40 m) 'cliffs', where the lateritic plateau meets the coastline, the majority of the coastline is low-lying and characterised by beaches, vast supra-tidal mudflats (saltpans), beach ridges, cheniers and aeolian dunes. The main river channels tend to approach the coast fairly directly and are circumscribed by the supra-tidal hypersaline mudflats. The Sandalwood River catchment, or Yiinkan Embayment, the location of the mounds discussed in this study, is the largest drainage system on the northern Mornington coastline (Figure 2).

The Yiinkan Embayment comprises mostly sandy red/yellow light textured earths overlying clay or weathered lateritic Mornington bedrock, with numerous swamps and swales on the northern side of the embayment that support heavier clay and loam-rich soils (Grimes and Sweet 1979). Characterised by saltpan and mangrove-fringed tributaries and estuaries (including the Sandalwood River), the embayment is adjacent to a rich marine environment. Sandy quartz residuals formed on laterite or beach rock platforms dot the saltpan, acting as sediment traps for catching sands and silts during seasonal strong south-easterly winds; otherwise the terrain is flat.

Methods

Magnetic susceptibility measures the ease with which a material can be magnetized in the presence of a magnetic field (Thompson and Oldfield 1986:25). It detects the magnetic minerals present in sediments making it an important proxy in archaeological studies (Dalan and Banerjee 1998; Evans and Heller 2003; Long *et al.* 1998). Sediment magnetic susceptibility can be raised through processes such as burning (both natural and cultural), weathering or pedogenesis, whereby organics introduced to a site are subsequently ingested along with sediments by microorganisms whose excretions cause the sediment susceptibility to increase (Fassbinder *et al.* 1990; Le Borgne 1955; Maher 1986; Tite and Mullins 1971).

While it has been predominantly used to identify sediment features and burnt material, and to define buried cultural layers (Fassbinder and Stanjek 1993; Dalan and Banerjee 1998; Gedye *et al.* 2000), Dalan (2008) described the broader potential of magnetic susceptibility studies in archaeology. Since the susceptibility signal is influenced by soil development, it has been shown to also provide a means for investigating soil formation factors and in turn site formation processes, including transition from the parent material, climate, topography, relief, living organisms (micro- or macro-) and time (Evans and Heller 2003; Thompson and Oldfield 1986). Therefore, assessing soil development through magnetic methods can potentially provide information on human impacts and how site features form and change, revealing variation in sediment input from cultural or natural processes (cf. Dalan 2008; Ellwood *et al.* 2004; Herries 2006; Linford *et al*. 2005).

The application of geophysical techniques to shell mounds only began in the last decade, and such approaches focused initially on the ability of instruments (especially ground penetrating radar (GPR)) to map the spatial layout or extent of shell midden features, or the depth of the shell deposits (Rodrigues *et al*. 2009; Santos *et al.* 2009; Thompson *et al.* 2004). To date, there are very little studies documented on the magnetic susceptibility of shell mound deposits (see Connah *et al*. 1976) and a reason for this may be due to their complex stratigraphy (Stein *et al.* 2003). While magnetic susceptibility studies on other types of open sites are common (see Connah *et al*. 1976 and references within), the lack of magnetic susceptibility studies on shell mounds is worth noting, especially because of the potential of this technique to provide information on depositional events.

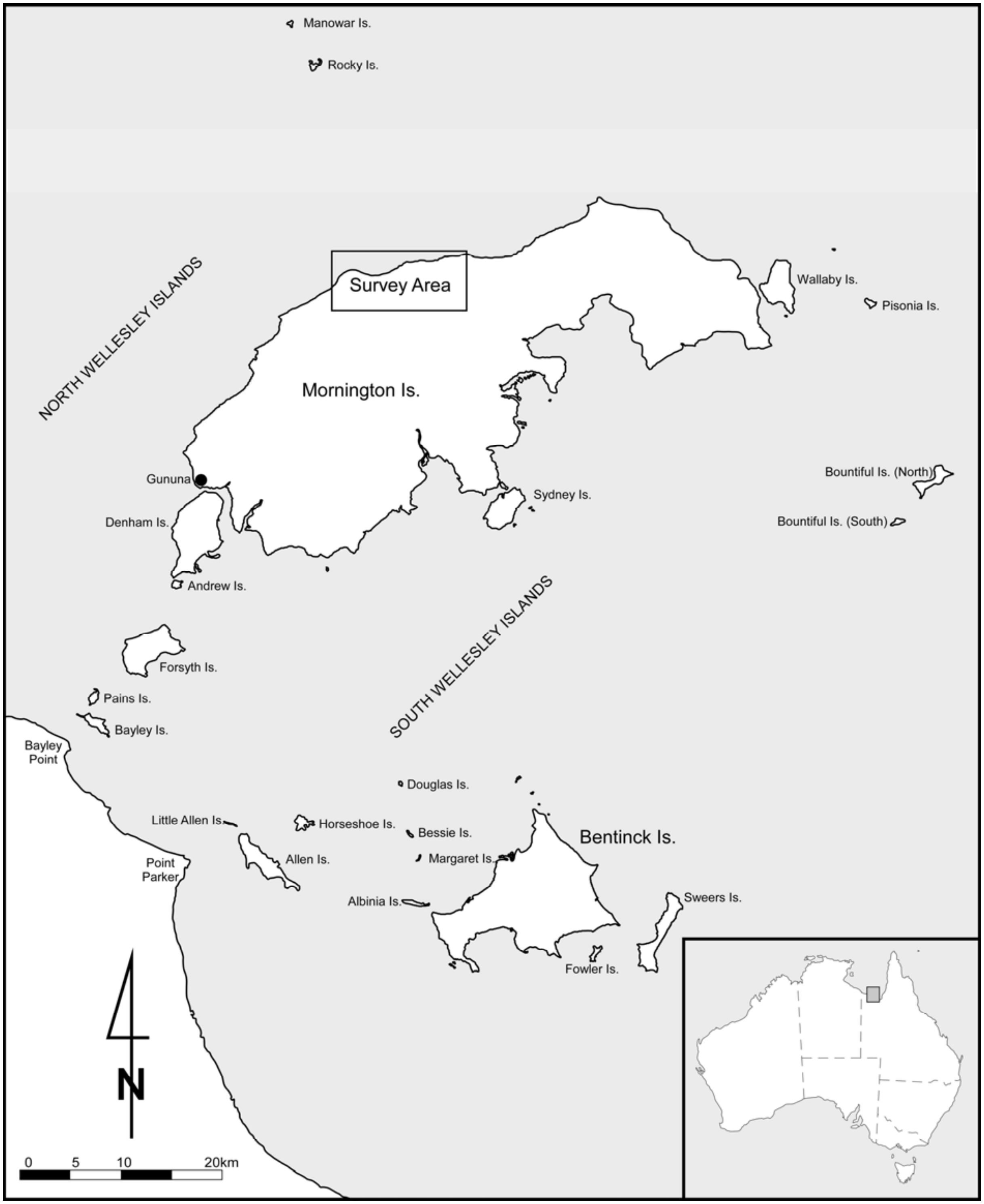

Figure 1. Map showing the Wellesley Islands in the Gulf of Carpentaria, northern Australia. Study area defined by box.

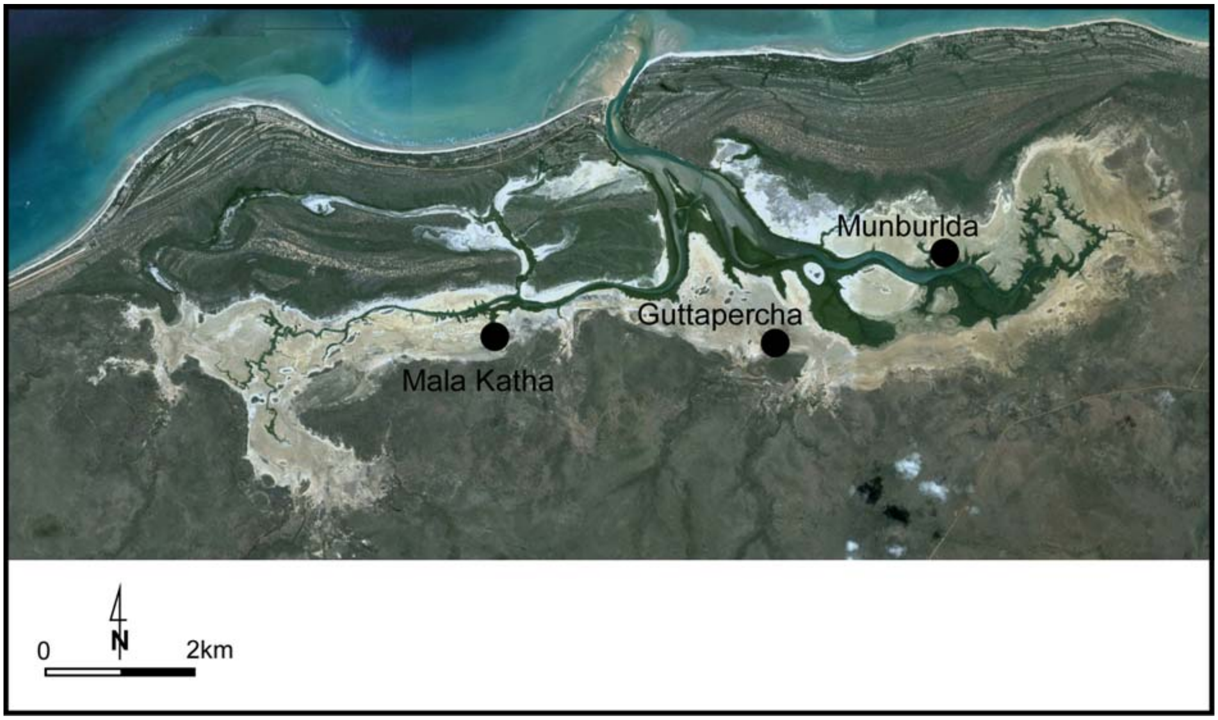

Figure 2. Yiinkan Embayment showing location of the three shell mound sites subject to this study (image sourced from Google™ earth).

Twenty-five shell mounds were recorded on the 21 km^2 hyper-saline mudflats of the Yinka Embayment, three of which—Guttapercha, Mala Katha and Munburlda—were chosen for detailed recording and sampling. All three sites were subject to some form of irregular supra-tidal inundation, with Mala Katha and Munburlda being completely submerged at times by seasonal king tides boosted by wet season run-off. A 1 m^2 test-pit was excavated at the Guttapercha site, while 50 cm square test-pits were excavated at each of the other sites using standard archaeological techniques detailed in Rosendahl (2012) (Figure 2). Excavation comprised small arbitrary excavation units (XUs or spits) averaging 2.8 cm in thickness within stratigraphic units. All three sites are subject to some form of irregular supra-tidal inundation, with Mala Katha and Munburlda being completely submerged at times by seasonal king tides boosted by wet season run-off. Radiocarbon ages for all sites were calibrated using OxCal 4.1.3 (Bronk Ramsey 2009) and the Marine13 dataset (Reimer *et al*. 2013), with a ΔR of -49±102 for marine samples (Ulm *et al*. in press). All calibrated ages are reported at the 95.4% age range. Details of the stratigraphy of each site are presented in Table 1 and radiocarbon ages in Table 2.

Sediments were described according to grain size, shape and roundness (after Briggs 1977). Approximately 2 g of the bulk sediment samples collected from each XU at each site were examined to quantify the presence of fine sands, silts and clays using a Beckman & Coulter, Multisizer™ 3 Coulter Counter. Samples were screened through a 1 mm sieve, underwent heating at 12 hours in a muffle furnace at 450ºC for the determination of organic values, and were then quartered randomly. In order to mitigate potential aggregation of sediments, 100– 50 ml of ISOTON II (an ionic diluent) was added to each sample, which was then subject to disaggregation in an ultrasonic bath. Sediments were suspended in solution using a magnetic stirrer, and an aliquot of approximately 10 ml was drawn up and then wet-sieved through a 355 µm mesh. Additional ISOTON II was added to achieve a solution concentration of 5–10% before processing for 20 seconds through the Multisizer using a 560 µm aperture tube (which measures 2–60% of the aperture size). Particle range distribution was established by sieving 20 g of sediment through a series of nested Endecotts sieves with parameters at coarse sand (CS) (1 mm–500 µm), medium sand (MS) (<500–250 µm) and very fine sand to silt (VFS-Si) (<125 µm).

Other sub-samples of each bulk sediment sample were packed into non-magnetic Althor P-15 boxes (5.28 cc volume) and measured using a Bartington Instruments Ltd MS3 Magnetic Susceptibility Meter with an MS2B Dual Frequency (460 and 4600 Hz) lab sensor. Repeat measurements were taken at a 0.1 range for each sample and averaged. Both low field mass (χ) and volume (SI) susceptibility measurements were taken, as well as frequency dependence of susceptibility (χfd). Frequency dependence is the difference between the measured magnetic susceptibilities of a sediment at low and high frequency, and is expressed as a relative loss of susceptibility (χfd = (χ460Hz-χ4600Hz), or a percentage loss of the low frequency value (χfd = (χ460Hz-χ4600Hz/χ460Hz*100) (Dearing *et al.* 1996; Maher 1986). In practice, this measurement shows the volume of ultrafine ferrimagnetic grains (i.e. magnetite or maghemite) known as superparamagnetic (SP) (Dalan and Banerjee 1998; Dearing *et al.* 1996; Maher 1986). Increases in χ in conjunction with χfd indicate an increase in the percentage of SP grains, which are often found in burned or developed surface soils. To avoid erroneous χfd values produced by instrument drift, a procedure of zeroing between each measurement was used. Since a magnetic field is being created for each measurement, the instrument was zeroed between each reading to calculate magnetic susceptibility.

Following methods outlined in Rosendahl *et al.* (2007), foraminiferal analysis was carried out on sediments from selected XUs within each stratigraphic unit to assess the integrity of deposits. A 10 g sub-sample of the bulk sediment was wet-sieved through 2 mm, 1 mm, 850 µm, 600 µm, 500 µm, 425 µm, 250 µm and 125 µm nested Endecotts sieves. For analysis, each sieved sediment fraction was transferred to a glass petrie dish and systematically examined along transects using a JNOEC stereo XTX-5 series C-type incident light binocular microscope. Identification of foraminifera and their habitats was assisted by reference to published texts (Albani 1979; Militante-Matias 1990; Murray 1991; Palmieri 1976; Sen Gupta 1999) and the online World Modern Foraminifera Database (Hayward 2013). Each foraminifera taxon was quantified by establishing the minimum number of individuals (MNI) based on counts of the umbilical phenotype. To facilitate comparison of the analysed sediments, densities are reported as the number of foraminifera per 100 g of sediment.

All excavated deposits were dry-sieved through 2.1 mm sieves in the field and brought back to the laboratory for sorting. Stone artefacts recovered from each excavation unit were analysed noting raw material type, length, width and height (see Rosendahl 2012). Other material collected and analysed included shell artefacts or worked shell, wood charcoal, fish bone, and shell (marine and bivalve). These criteria were also used to help distinguish the cultural origins of the mounds (after Attenbrow 1992:4; Gill *et al.* 1991:335; Rosendahl *et al.* 2007; Ulm 2006).

Table 1. Stratigraphic unit descriptions

Site	Depth (cm)	Stratigraphic Unit (SU)	Description
Guttapercha	0-31	SUI	Reddish brown (5YR 4/4) poorly sorted, sub-angular medium sand. Dark brown (7.5YR 3/4) at unit base. pH ranges from 8.5-9.
	31-51	SUII	Brown (10YR 4/3) to dark yellowish brown (10YR 4/6) poorly to medium sorted, sub-angular medium sand. Sub-rounded, fine sands from 27-46 cm. pH ranges from 8.5-9.
	51-120	SUIII	Culturally sterile mudflat with frequent small articulated bivalves including *Tellina* sp. and *Gafrarium* sp., all preserved *in situ* growth position. Yellowish brown (10YR 5/6) sub-rounded, poorly sorted coarse to fine sand. pH ranges from 8-8.5.
Mala Katha	0-22	SUI	Brown (10YR 4/3) poorly sorted, sub-angular medium to fine sand in upper 17 cm, shifting to poorly sorted, fine sand. Dark yellowish brown (10YR 4/4) at unit base. pH ranges from 8.5-9.5.
	22-38	SUII	Culturally sterile. Dark yellowish brown (10YR 4/4) poorly sorted, sub-angular fine sand. Yellowish brown (10YR 5/6) at unit base. pH was 9 near unit top, 8.5 at base.
Munburlda	0-26	SUI	Brown (7.5 YR 4/2) to dark greyish brown (10YR 4/2) well-rounded, fine silty clay. Brown (10YR 4/3) at unit base. Dense charcoal stain at 13 cm. pH ranges from 8.5-10.
	26-40	SUII	Culturally sterile clay-mudflat with numerous articulated bivalves (*Tellina* sp.), *in situ* growth position. Brown (10YR 4/3) to dark yellowish brown (10YR 4/6) well-rounded, fine silty clay. pH ranges from 8.5-9.

Table 2. Radiocarbon Dates. ~ = AMS.

Site	Depth (cm)	Stratigraphic Unit (SU)	Sample Material	Lab No.	^{14}C Age	Calibrated Age BP (95.4% probability)
Guttapercha	2.9	SUI	*Anadara antiquata*	Wk-23122	2015±38	1376-1885
	22.5	SUI	*Anadara antiquata*	Wk-30543	1959±39	1325-1823
	46.2	SUII	*Anadara antiquata*	Wk-23123	2459±49	1875-2449
	52.8	SUIII	*Tellina* sp.	Wk-23124~	4124±30	3938-4526
Mala Katha	3.3-6.2	SUI	*Polymesoda (Geloina) coaxans*	Wk-23125	876±36	315-684
	20	SUI	*Polymesoda (Geloina) coaxans*	Wk-23126	1266±37	654-1087
Munburlda	0-1.8	SUI	*Anadara antiquata*	Wk-23127	1337±34	708-1169
	22.2-24	SUI	*Anadara antiquata*	Wk-23128	1484±37	868-1299

Results

Guttapercha

The largest mound recorded on the Sandalwood River saltpan, Guttapercha has a diameter of 25 m and rises ~1 m above the surrounding land surface (Figure 3). The surface of the mound exhibited a high density scatter of large estuarine gastropods dominated by *Terebralia* spp. and *Telescopium telescopium*, with some bivalves including *Polymesoda coaxans*, *Anadara antiquata* (cockle shell) and *Gafrarium* sp., and a small number of stone artefacts.

As summarised in Table 1, excavation revealed three stratigraphic units (SU), with cultural materials including shell, stone artefacts, fish bone and charcoal present in both SUI and SUII (Figures 4 and 5). Culturally sterile sediments were encountered in SUIII at a depth of 51 cm below mound surface, incorporated into which were articulated *Tellina* sp. shells in growth position which returned an age of 3938-4526 cal BP (Wk-23124; see Table 2), indicating the saltpan had developed by that time. Samples of *A. antiquata* from 2.9, 22.5 and 46.2 cm below surface produced radiocarbon ages of 1376-1885 cal BP (Wk-23122) (SUI), 1325-1823 cal BP (Wk-30543) (SUI) and 1875-2449 cal BP (Wk-23123) (SUII), respectively (Table 2). There was no visible evidence of any hiatuses in the sequence, i.e. culturally sterile layers such as dark soil or sand horizons as observed elsewhere (Morrison 2010, 2013).

The radiocarbon ages indicate the cultural deposits at Guttapercha were deposited between ~1600 and ~2200 cal BP. Given that the underlying saltpan sediments were in place by ~4200 cal BP, this site was therefore first occupied some 2000 years after the last major phase of local landform development. The uppermost stratigraphic unit (SUI), comprising the densest cultural material, accumulated rapidly in less than 100 years, approximately 1600 years ago, with no stratigraphic evidence for separate depositional events occurring during that time.

Sediment size analysis demonstrated the majority of sediments (50% or greater) throughout the Guttapercha deposit are very fine quartz sands and silts, indicating a consistent seasonal aeolian sediment supply to the site (Figure 4). Analysis of the silt-sized particles (62.5–7.8 µm) showed a consistent 70% in the coarse silt range.

As shown in Figure 5, magnetic susceptibility analysis revealed several increases in χ in the upper, central and lower XUs of SUI, while values were consistently lower in SUII and SUIII. A slight increase in the basal unit (take from an auger core that allowed the sampling of sediments at a depth lower than that achieved in the excavation itself) is likely to be a natural signal driven by *in situ* decay of ironstone in the sediment matrix. The higher χ values in the upper and lower XUs of SUI correspond well with similar increases in stone artefacts, wood charcoal, fish bone and shell. The frequency dependence of susceptibility also increases at Guttapercha only in the upper and lower XUs of SUI, directly below the interface between SUI and SUII, and at the interface between SUII and SUIII. There are also slight increases in the central XUs of both SUII and SUIII. The lower χ and χfd in SUII and SUIII correspond with increases in very fine sands and silts, and decreases in artefactual material.

The only correlation where we see an increase in both χ and χfd is directly below the interface between SUI and SUII, indicating a change in the fine-grained component of magnetic grains at this depth which could represent a developed surface. Since all increasing χ values in SUI do not have a corresponding increase in χfd, it is apparent that magnetic enhancement is not a result of the presence of fine-grained ferrimagnetics. Sediment size analysis reveals that as χ increases, so too do the medium-coarse sands. This suggests that a depositional processes largely involving humans account for these magnetic variations, as we would expect archaeological materials to lie in the coarse fraction textural size. A bivariate plot (see Figure 6) of χ to χfd provides information on the relationships between the two parameters and the proportion of fine SP grains. For Guttapercha, the χfd is between 0.77–3.05%, suggesting that the sediments are low in SP grains (cf. Dearing *et al.* 1996). These low percentages overall likely reflect young soils, since it has been shown elsewhere that young soils have low percentages in χfd (Dalan 2006; Dearing *et al.* 1996).

Foraminiferal analysis was carried out on sediment samples from XUs 2, 5, 8, 11, 17, 20 and three SUIII samples collected by auger (Figure 5). In total, two (25/100g) foraminifera were identified in XU2 (2.3 cm below surface), with 26 (233/100g) and 52 (422/100g) in two of the auger samples (those taken at 100 cm and 120 cm, respectively); no foraminifera were identified in the other examined samples. Foraminifera density in the SUIII samples is well below that expected for high energy/wave deposited natural units of >1000/100 g, such as were recorded for chenier deposits on the central Queensland coast, but still well above the parameters established for cultural coastal deposits (Rosendahl *et al.* 2007). Coupled with the sediment size analysis and abundance of pisoliths formed through episodic saturation, the foraminiferal concentration reveals low energy tidal deposition in SUIII (i.e. below the cultural deposits), as opposed to a high energy wave-deposited concentration, with no evidence for post-depositional marine disturbance of the cultural deposits of the mound excepting low-energy seasonal inundation. Individual foraminifera were too eroded to allow identification to taxon level.

Figure 3. Guttapercha shell mound, context image.

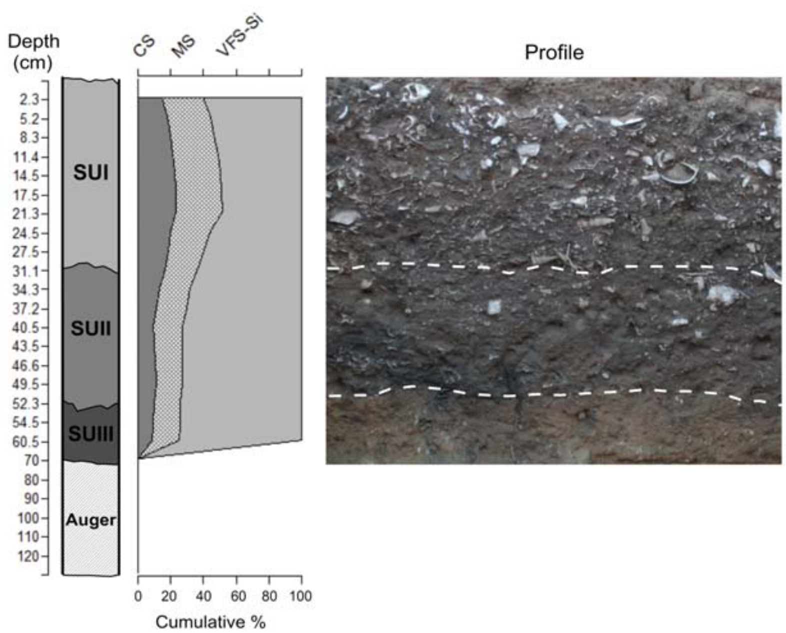

Figure 4. Sediment profile and particle size distribution of Guttapercha. Note that samples below 60 cm were augered beyond the base of the excavation. CS=coarse sands; MS=medium sands; VFS-Si=very fine sands and silts.

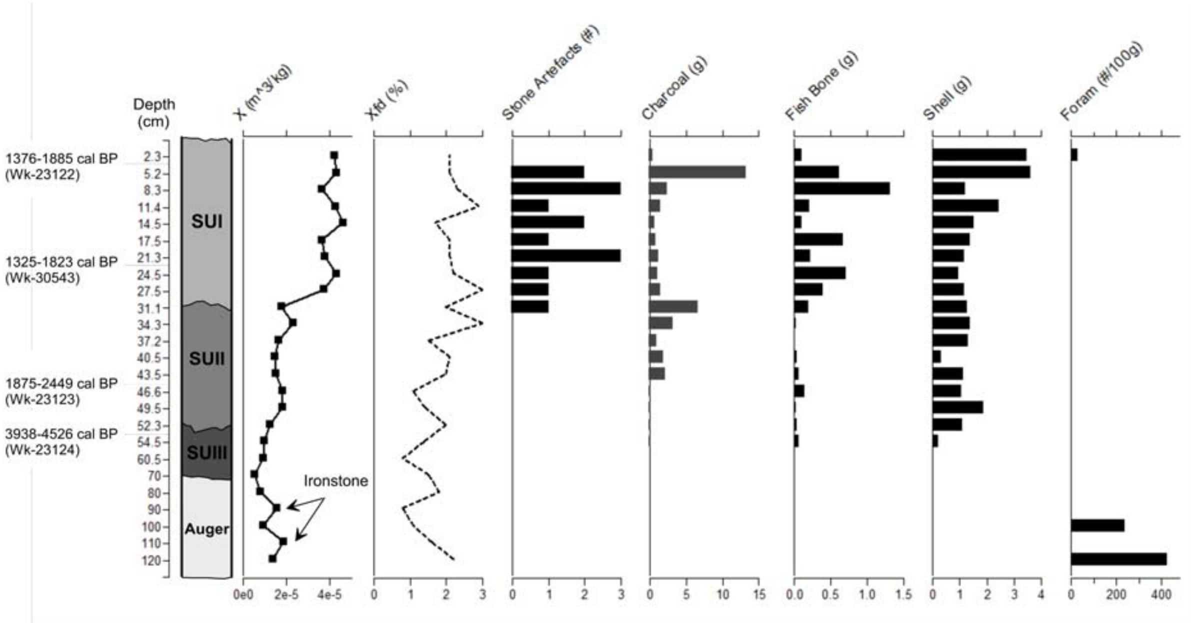

Figure 5. Combined geoarchaeological and geophysical data at Guttapercha.

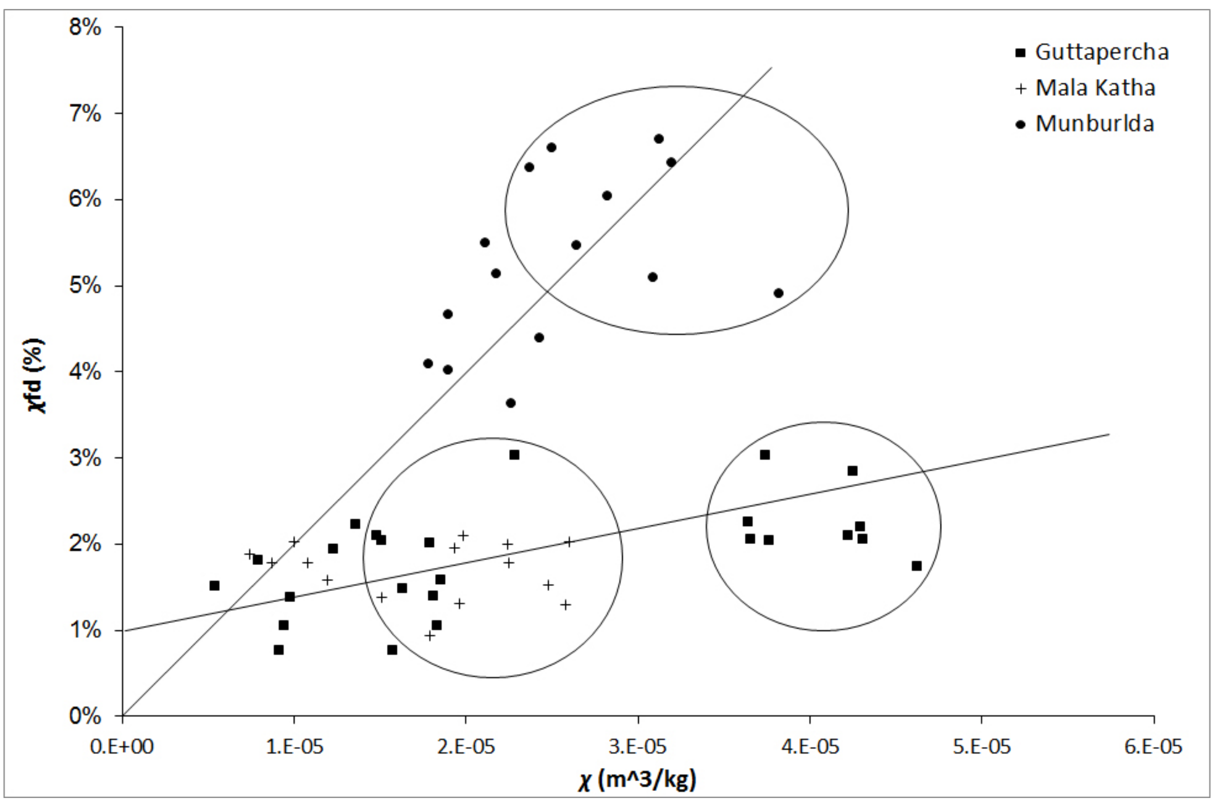

Figure 6. Bivariate plot showing the relationship between χ with χfd for Guttapercha, Munburlda and Mala Katha. Circled data represent SUII and SUIII.

Munburlda

Munburlda is one shell mound amongst a cluster of such sites along the eastern branch of the Sandalwood River. Rising 45 cm above the surrounding substrate, it had a diameter of 10 m. Surface inspection gave the impression it was dominated by *A. antiquata*; however, excavation revealed co-dominance between the latter and *Saccostrea glomerata* (oyster). Other marine shell taxa present included the bivalves *Isognomon* sp*. and Marcia hiantina*, and gastropods *Terebralia* spp., *Telescopium telescopium*, *Melo amphora* (baler) and *Syrinx aruanus* (trumpet shell). Like Guttapercha, a small number of stone artefacts were observed on the surface of Munburlda.

Excavation revealed two stratigraphic units: SUI, an upper shell-rich cultural deposit which includes shell, fish bone, stone artefacts and charcoal, and SUII, a lower culturally sterile mudflat sediments commencing at 26 cm below surface (Figure 7 and Table 1). Again, incorporated into the base of SUII were articulated *Tellina* sp. shells in growth position. Samples of *A. antiquata* from 0–1.8 and 22.2–24 cm below surface revealed a period of shell deposition lasting ~150 years, between 708-1169 and 868-1299 cal BP (Wk-23127 and Wk-23128, respectively; see Table 2).

Sediment analysis clearly illustrates an altered sediment supply between the lower saltpan unit (SUII) and the upper cultural unit (SUI) (Figure 7). The percentage of sediments comprising very fine quartz sands and silts was 40% in SUI, doubling to 80% in SUII. Multisizer results indicate no obvious change in the silt fraction, with 75% of grains falling within the medium silt range throughout the deposit. This suggests a relatively continuous deposition of sediments from low energy supra-tidal activity throughout the sequence, with the commencement of aeolian sedimentation in SUI as the build-up of shells started to act as a sediment trap.

The magnetic susceptibility results revealed increases in χ only in the upper XUs of SUI, which corresponded with increases in stone artefacts, fish bone, shell and, in particular, wood charcoal (Figure 8). As with Guttapercha, the values were lower in SUII and corresponded to increases in very fine sands and silts. With the exception of shell, both artefactual material and χ values decrease with depth; alternatively, shell increases slightly before dropping off in SUII. The frequency dependence of susceptibility increased only in the central and lower XUs of SUI and in the central portions of SUII. These values decrease slightly at the interface between SUI and SUII with a change in sediment.

There is no positive correlation between χ and χfd at Munburlda. Instead, where χ increases we see the opposite, i.e. a decrease in χfd, demonstrating that magnetic enhancement is not a result of the presence of fine-grained ferrimagnetics. The sediment size analyses revealed that the increase in χ near the upper XUs of SUI corresponded closely with an increase in very fine sands and silts, and not in medium-coarse sands as was the case at Guttapercha. While these increases are largely a result of anthropogenic inputs (since artefactual material increases are evident), the changes in textural size could reflect an accumulation of either aeolian or alluvial sediments that may have overprinted the archaeological material. Further analysis of the magnetic minerals themselves is required to determine this. The bivariate plot shows that Munburlda's sediments range in χfd between 3.65–6.79% and trend more towards χfd than χ, suggesting a greater proportion of SP grains in the assemblage, but overall lower concentrations of SP grains in general (see Figure 6).

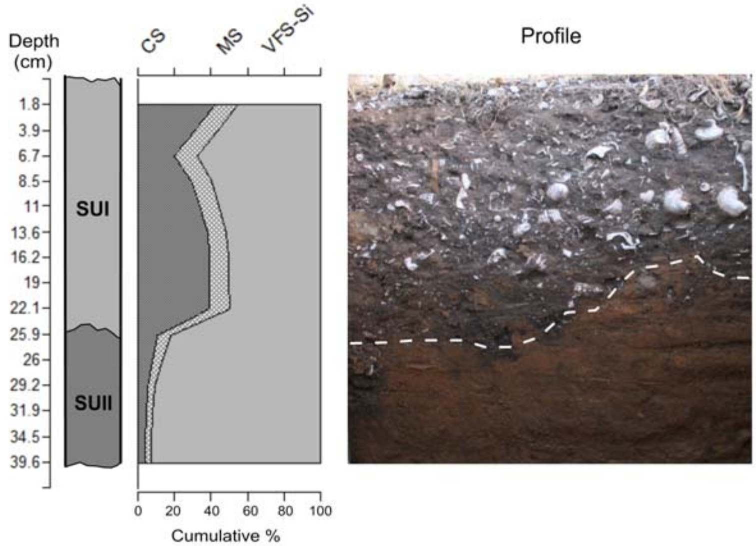

Figure 7. Sediment profile and particle size distribution of Munburlda, Square A.

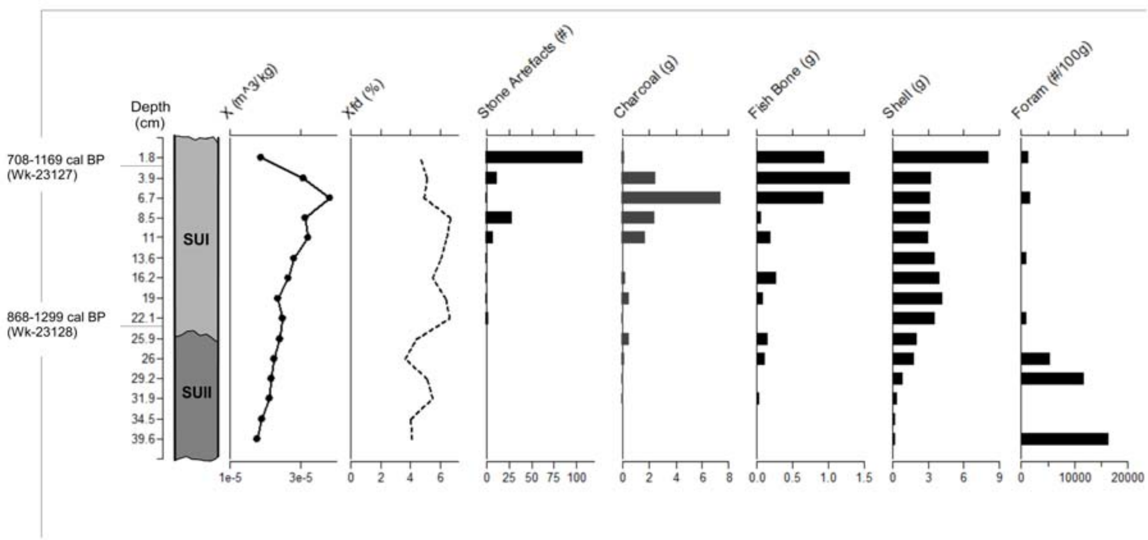

Figure 8. Combined geoarchaeological and geophysical data at Munburlda.

Foraminiferal analysis was carried out on XUs 1, 3A, 6, 9, 10, 12 and 15A, with a total of 1027 foraminifera identified in across all XUs (Figure 8). The cultural XUs of SUI (0–26 cm) exhibited a density of <1600/100 g, with the lower SUII (26–40 cm) exhibiting a density >10,000/100 g with XU10 representing a mixed unit with a foraminifera density of 5240/100 g. The overall assemblage is indicative of a supra-tidal estuarine zone as determined by the abundance of *Quinqueloculina* spp., including *Q. seminula*, along with *Elphidium hughesi* (Wang and Chappell 2001).

Mala Katha

Mala Katha, the smallest of the excavated shell mounds recorded on Mornington Island, measured 13 by 5 m and rose ~37 cm above the surrounding substrate. It is situated along the southern margin of the saltpan, in the vicinity of several other shell mounds and bioherms. The surface of the mound exhibited a high density marine shell scatter dominated by *Polymesoda coaxans*, *Terebralia* spp. and *Telescopium telescopium*. *Anadara antiquata* and *Gafrarium* sp. were also present in small quantities, along with a small number of stone artefacts.

Again, two stratigraphic units were present: an upper, homogenous cultural unit including shell, fish bone and charcoal to 22 cm below surface (SUI), and culturally sterile sediments (SUII) beneath 22 cm (Figure 9 and Table 1). Two samples of *P. coaxans* from 3.3–6.2 and 20 cm, produced radiocarbon determinations of 315-684 and 654-1087 cal BP (Wk-23125 and Wk-23126, respectively; see Table 2), indicating that Mala Katha accumulated between ~800 and 500 cal BP.

Sediment analyses demonstrate a demarcation between the stratigraphic units, with SUI containing higher percentages of medium to coarse sands than SUII, which is dominated by very fine sands and silts (<80%) (Figure 9). The decrease in very fine sands in SUII moving up into SUI, likely shows the shell mound acting as a sediment trap accumulating larger sands. Multisizer results show no obvious change in the proportions of coarse, medium and fine silts, with SUI sediments exhibiting 90% of grains <42 µm and SUII sediments exhibiting 90% <41 µm. The particle size range present identifies the presence of both wind-borne sands and water-deposited silts, and suggests relatively consistent low energy water deposition with an increase in aeolian sedimentation in SUI.

As shown in Figure 10, the magnetic susceptibility analysis revealed several χ increases in the upper, central and lower XUs of SUI. Again, values were lower in SUII and correspond to increases in very fine sands and silts; as χ increases so does the coarse fraction. The higher χ values in the central to lower XUs of SUI corresponds closely with increases in stone artefacts, wood charcoal, fish bone and shell. These values were associated with a high level of charred shells in the deposit, which were associated with soil staining observed during excavation. The χ increases in the upper XUs of SUI corresponded only to increases in fish bone and shell, while the χ increase at the bottom of SUI corresponded only to an increase in very fine sands and silts. All the frequency dependence of susceptibility increases occur in SUI, although for SUII, χfd percentages are generally high with depth.

The correlating increases in both χ and χfd in SUI indicate that there is a slight increase in the fine-grained component of magnetic grains within this unit. While some artefactual material is present in the upper XUs of SUI, the slight decrease in medium-coarse sands and increase in both χ and χfd could indicate a developed surface (e.g. pedogenesis) or sediment change. The χ increases that occurred directly below this represent changes to anthropogenic inputs, as supported by increases in quantities of artefactual material and the soil staining. The higher χfd percentages and low χ values in SUII are likely derivative of sediment changes (increase in very fine sands and silts). Like Guttapercha, the χfd of Mala Katha's sediments are low, ranging between 0.94–2.11%. This demonstrates that the sediments are low in SP grains and again may reflect young soils (see Figure 6). Although SP grains give a higher χ, all the site's sediments have similar χ values despite Guttapercha and Mala Katha having lower χfd. This indicates that ferrimagnetic concentrations are lower in those two sites. Foraminifera analysis was carried out on samples from XUs 2, 5, 8, 11, 14 and 16 (Figure 10) with very low densities recovered. Two foraminifera (26/100 g) were recovered from XU5 (10.48 cm), and 1 (12/100 g) from XU8 (17.2 cm). No foraminifera were recovered from the SUII sediments.

Discussion

There is a strong relationship between depositional processes and magnetic properties at all three shell mound sites in the Yinkan Embayment. Artefact-rich deposits should logically have a higher magnetic susceptibility than sterile deposits due to their having either a higher organic content (associated with by bacterial microorganisms) or burned sediments resulting from either cultural or natural fires on the three shell mounds. However, natural pedogenesis can also cause an enhanced susceptibility signal (Dalan 2008; Evans and Heller 2003).

It is clear from that the observed magnetic enhancement is related to several factors. Positive correlations with artefactual material was the best proxy for determining magnetic variations that were more likely anthropogenic in origin than natural. Correlations with changes in grain sizes indicated that some of the increased magnetic values could result from changes in sediment sources (e.g. aeolian or alluvial). Where we see increases in both χ and χfd indicate increases in the fine grained component of the sediments, which ould reflect either pedogenesis or burning (natural or cultural), however weathering processes may also account for this.

There were changes apparent within stratigraphic units, particularly those units containing the abundance of archaeological materials (e.g. stone artefacts, fish bone, wood charcoal and shell). There tended to be a general distinction not only in colour between stratigraphic units, but also changes in sediment size (often with increasing medium to coarse sands rising upwards through the profiles) and susceptibility values. Overall, these observations suggest that the sites retain a high degree of integrity.

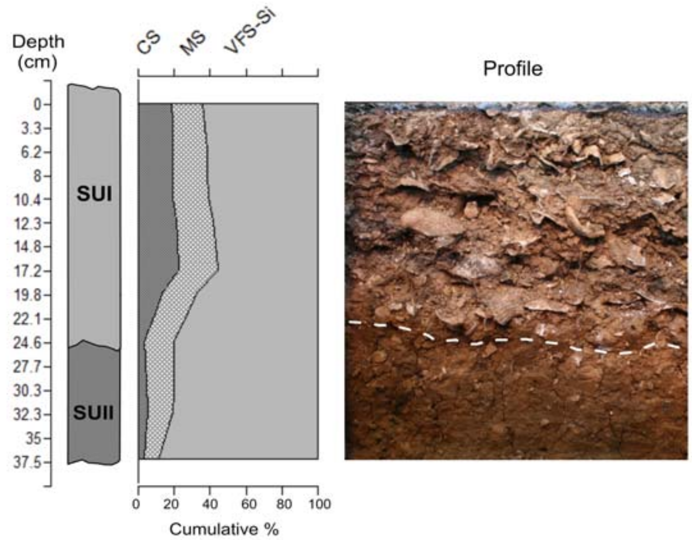

Figure 9. Sediment profile and particle size distribution of Mala Katha.

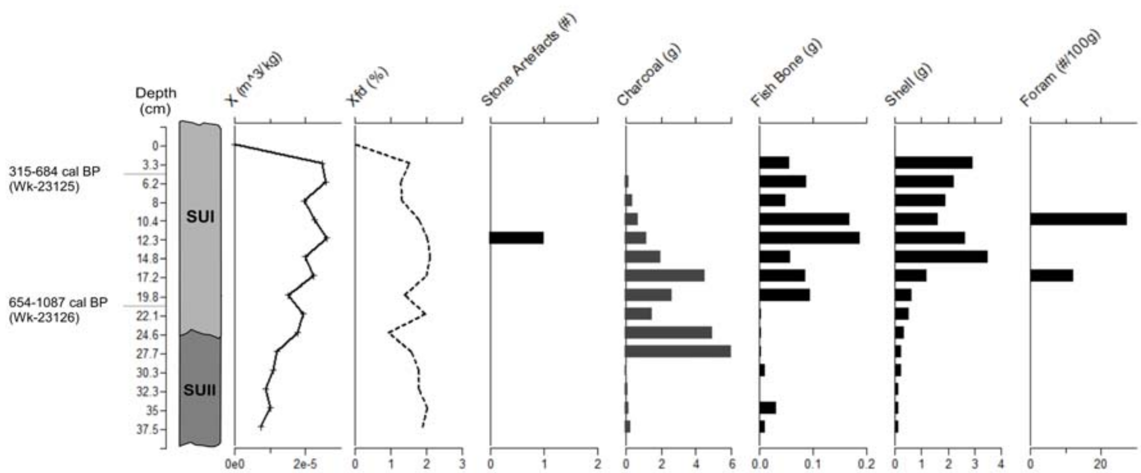

Figure 10. Combined geoarchaeological and geophysical data at Mala Katha.

Correlations between increases in χ in conjunction with χfd, as indicators of either cultural (burned) or natural (well-developed soils) inputs, were apparent at Guttapercha and Mala Katha. Changes in artefactual and sediment size data correlated with increased susceptibility values were the best indicators of human occupation, demonstrating that fine-grained magnetic grains are not responsible for the increase in susceptibility (we had initially anticipated that increased susceptibility values might be the result of the presence of larger magnetic grains).

From the integrated data sets, we can infer that both Guttapercha and Mala Katha showed repeated occupation within their uppermost stratigraphic units. This is confirmed by increases in magnetic susceptibility values and quantities of fish, artefactual stone, wood charcoal and shell (Rosendahl 2012). Given the available data, it is difficult to determine that multiple occupations events had occurred at Munburlda based solely on the susceptibility data. Despite low χ values at the bottom of SU1, the presence of artefactual material and increases in the coarse fraction of the sediments indicates the onset of human occupation.

In the study area, McKnight (1999:89) noted that 'shellfish were consumed during the rainy season, when the tides were exceptionally high'. He specifically noted that the Yinkan Embayment was a place where shell was 'consumed', rather than where people camped. This proposal was supported by oral testimony provided by Cyril Moon, Lardil elder (pers. comm., June 2013). Elsewhere, Lowe and Fogel (2010:250) observed episodic deposition in ditch fill in the Northern Plains of North America using magnetic susceptibility. They found that high χ values correspond to occupational layers and low χ values correspond to windblown culturally sterile in-fill. While we see a similar χ trend at Guttapercha and Mala Katha (increases in χ followed by abrupt decreases), based on the available data it is difficult to ascertain the rate and periodicity of visitation.

Further research examining the magnetic variations associated with anthropogenic inputs and sediment changes using other magnetic parameters would enhance the results. It would also be productive to investigate whether anthropogenic inputs are being overprinted by other sediment sources and if episodic deposition is taking place using micromorphology and x-ray diffraction (XRD). One thing is clear, however; people used these mounds more than once resulting in discrete deposition events that are apparent in the sedimentary and magnetic data, even though the macroscopic data suggested deposition was continuous.

Conclusion

Change as represented in the Australian archaeological record is, in most cases, subtle, with cultural change represented through nuanced changes in the subsistence economy and/or tool production, rather than through the emergence of new architectures, monuments or evidence of large-scale technological and societal change. As a consequence, archaeologists are increasingly turning to multidisciplinary approaches to maximise the amount and resolution of data obtainable, to provide a more informed understanding of the past.

Numerous studies have focused on assessing depositional processes of, and post-depositional disturbance to, Australian archaeological sites. When identifying patterns of change through time, studies of open sites tend to focus only on the macroscopic cultural materials, i.e. shells and stone artefacts, correlated with gross stratigraphic change supported by radiocarbon chronologies. The pitfalls of these approaches is that shell matrix sites typically have a homogenous stratigraphic profile with overlapping or close radiocarbon dates that denote rapid, 'archaeologically instantaneous' site formation. These factors lead to the interpretation of single event or rapid short-term deposition, or unchanging site use through time.

This pilot project has highlighted the benefits of integrating geoarchaeological approaches, including magnetic susceptibility, to help establish subtle changes in shell mounds of the Yinkan Embayment were repeatedly visited, despite radiocarbon dates suggesting effectively 'archaeologically instantaneous' deposition. As open sites are increasingly being relied on to establish regional chronologies and identify change through the mid- to late Holocene in Australia, it is paramount that robust techniques be implemented to characterise the complex depositional processes that contribute to the formation of these sites. This analysis improved our understanding of the depositional history of the Guttapercha and Mala Katha sites, and has important implications for studies of shell mounds elsewhere, where the limitations of radiocarbon dating precision may similarly mask multiple deposition events.

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